PRICE 40 CENTS*

RCA PHOTOCELLS

SOLID-STATE PHOTOSENSITIVE DEVICES

RADIO CORPORATION OF AMERICA
ELECTRONIC COMPONENTS AND DEVICES, HARRISON, N. J.

*Suggested Price

CSS-800 (replaces ICE-261 series)

INTRODUCTION

This revised catalog contains concise, tabulated data describing RCA cadmium-sulfide photoconductive cells, germanium p-n alloy photojunction cells, and silicon N on P photovoltaic cells. Accompanying the data are dimensional outlines, dc resistance curves, and photographs of each photocell in actual size.

A section describing photoelectric measurements of both visible and radiant energy is included in this revision. Another section describes the construction and characteristics of RCA photocells.

Also contained in this catalog are tabulated data on tungsten light sources, a photocell replacement guide, and schematic diagrams of representative circuits using RCA photocells.

For complete technical data on RCA Commercial Photocell Types, write RCA, Commercial Engineering, Harrison, N.J. For the latest technical information on RCA Development Types, write **Market Manager, Photocells, RCA; Lancaster, Pa.** When requesting such information, please specify the types in which you are interested.

Commercially available RCA related photoemissive devices are described in catalog "RCA Photo and Image Tubes", 1CE-269, and in "RCA Phototubes and Photocells", PT-60, which may be obtained from your local RCA Tube Distributor or from RCA, Commercial Engineering, Harrison, N.J.

TYPICAL APPLICATIONS

- Control Circuits
- Logic Circuits
- Street-and Yard-Light Controls
- Iris Controls
- Laser Detectors
- Switches
- Light Flashers
- Level Indicators
- Remote Potentiometers
- Annunciator Systems
- Light Meters

GENERAL INFORMATION

PHOTOCONDUCTIVE CELLS

Cadmium-Sulfide Broad-Area Types

Photocells of this type are also known as photoresistors or light-dependent resistors. They utilize a polycrystalline photosensitive surface and are characterized by high sensitivity to visible radiation and moderate speed of response to changes in illumination. They find extensive use in control circuits where it is desired that changes in incident light control relays directly, in reading punched cards at moderate speeds, in automatic iris controls in photographic cameras, and in automatic street-light and yard-light controls.

PHOTOJUNCTION CELLS

Germanium P-N Alloy Junction Types

These photocell types have good sensitivity, and a speed of response to changing light signals that is well beyond the audio range. Cells of this type are recommended for applications such as sound pickup from motion-picture film, and in near-infrared applications.

Silicon N on P Diffused Junction Types

Photocells of this type are used primarily for the direct conversion of solar radiant power into electrical power, in light-measuring and light-operated-control applications, in near-infrared laser detectors, and in applications where high temperatures are encountered. They have good stability and do not require an external power supply.

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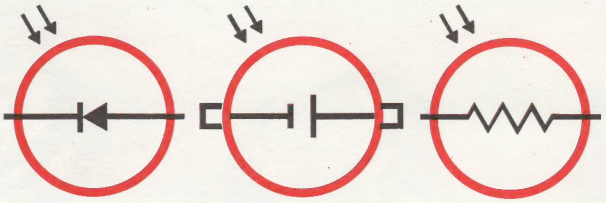

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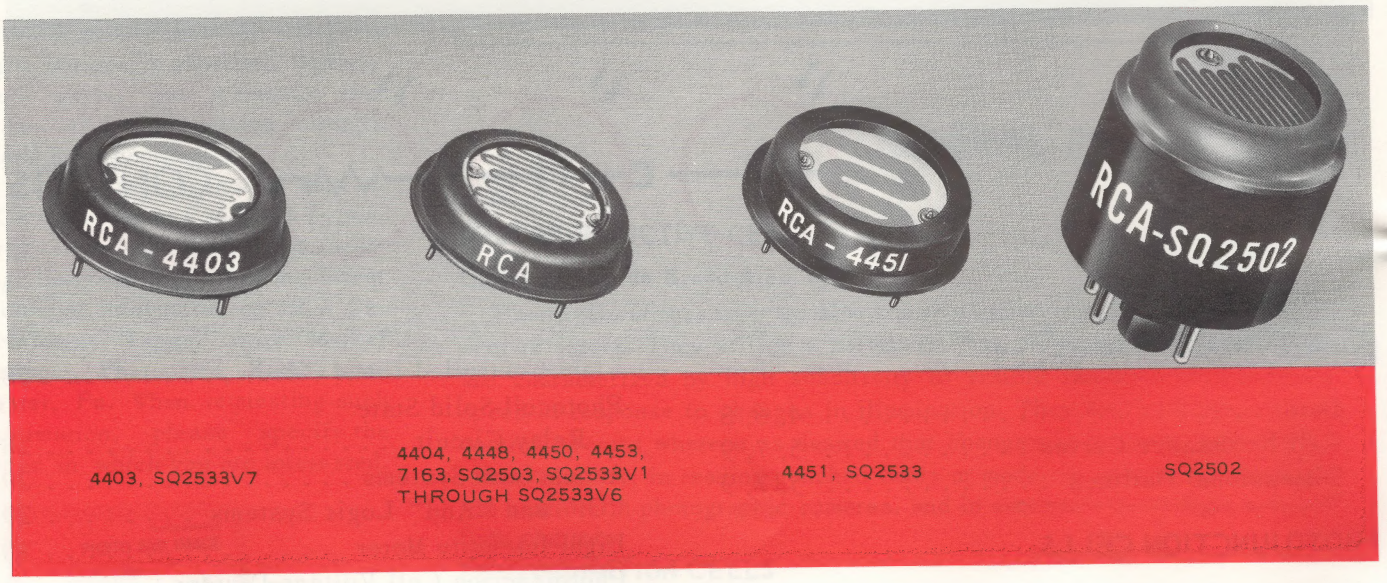
1" - Diameter Broad-Area Cadmium-Sulfide Photoconductive Cells

RCA TYPES		Spectral Response	MAXIMUM RATINGS				CHARACTERISTICS AT 25° C				
Glass-Metal Types[a]	Plastic-Filled Glass-Metal Types[b]		Voltage Between Terminals DC or Peak AC volts	Power Dissipation[c] watt		Photo-current ma	Voltage Between Terminals ac volts	Illumi-nation[e] foot-candles	Photocurrent[f] ma		Max. Decay Current[g] μa
				Continuous Service	Demand Service[d]				Min.	Max.	
4451	SQ2533	S-15	600	0.75	1.0	50	50	35	2	3.5	40
4450	SQ2533V1	S-15	600	0.75	1.0	50	50	3.5	2	3.5	40
SQ2503	SQ2533V2	S-15	600	0.75	1.0	50	50	1	0.8	1.7	40
7163	SQ2533V3	S-15	600	0.75	1.0	50	50	1	1	3	40
4448	SQ2533V4	S-15	600	0.75	1.0	50	50	1	1.5	4	40
4404 SQ2502[h]	SQ2533V5	S-15	600	0.75	1.0	50	50	1	2.5	5	40
4453	SQ2533V6	S-15	600	0.75	1.0	50	50	1	3	7	40
4403	SQ2533V7	S-15	250	0.75	1.0	50	50	1	8	16	78



4403, SQ2533V7

4404, 4448, 4450, 4453, 7163, SQ2503, SQ2533V1 THROUGH SQ2533V6

4451, SQ2533

SQ2502

a The maximum ambient operating temperature range for these cells is −75° C to +75° C.

b The maximum ambient operating temperature range for these cells is −40° C to +75° C.

c With sensitive surface of cell fully illuminated. These dissipation ratings apply up to a temperature of +40° C from which point the cells are derated linearly to 0 watts at +75° C.

d The demand rating is a dissipation rating to which the cell may be exposed in outdoor applications. The rating may be utilized twice every 24 hours for a period of 20 minutes each time provided the interval between demand periods is not less than 4 hours.

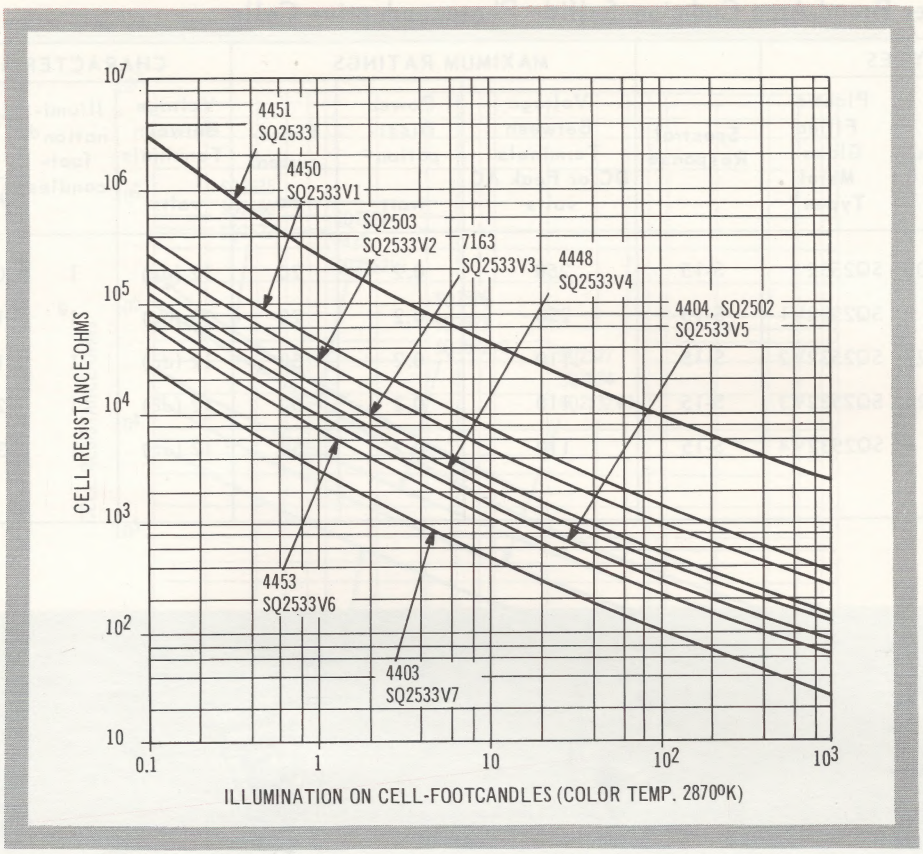
e For conditions where light flux from a tungsten-filament lamp operated at 2870° K is transmitted through a filter (Corning C.S. No. 1-62 which has an effective transmission of luminous flux of 13.3%) onto the sensitive surface. The value of illumination incident on the sensitive surface is 7.5 footcandles measured before positioning the filter between the lamp and the cell. The sensitive surface of the cell is fully illuminated.

f This characteristic is determined after the cell has been exposed for a period of 16 to 24 hours to 500 footcandle illumination (white fluorescent light).

g Measured 10 seconds after removal of incident-illumination level.

h For renewal use only. Not for new equipment design.

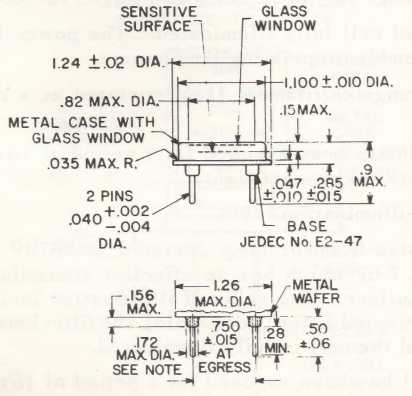
Illustrations show actual photocell size.



DC Cell Resistance of 1" - Diameter Broad-Area Photoconductive Cells as a Function of Cell Illumination

DIMENSIONS IN INCHES

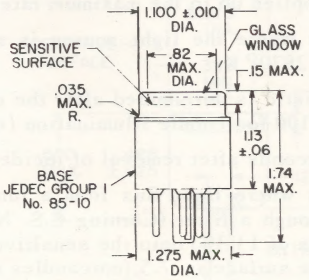
GLASS-METAL TYPES



NOTE: FOR SOCKET DESIGN, PROVIDE CLEARANCE HOLE HAVING MINIMUM DIAMETER OF 0.188''.

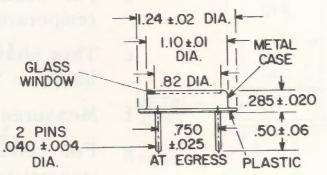
4403, 4404, 4448, 4450, 4451, 4453, 7163, SQ2503

GLASS-METAL TYPES



SQ2502

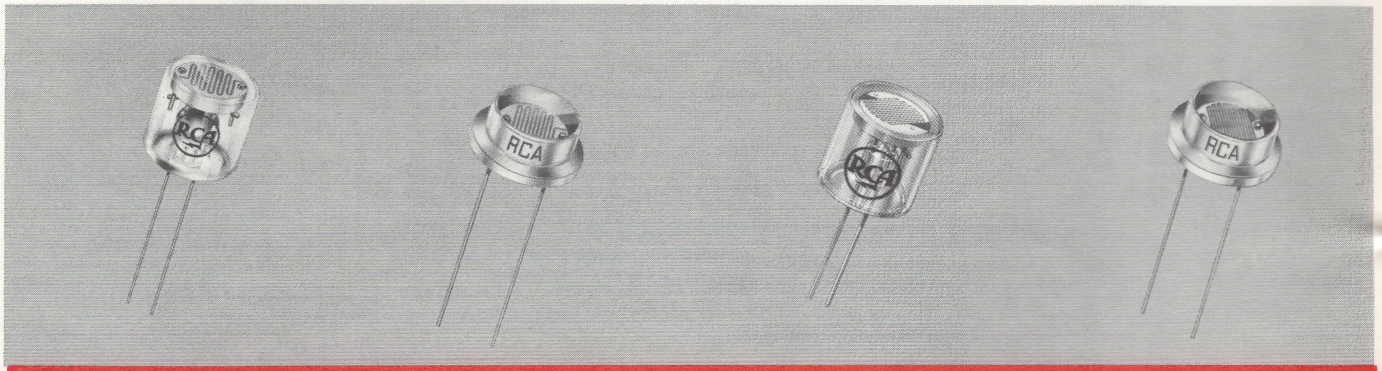
PLASTIC-FILLED GLASS-METAL TYPES



SQ2533, SQ2533V1, SQ2533V2, SQ2533V3, SQ2533V4, SQ2533V5, SQ2533V6, SQ2533V7

1/2"-Diameter Broad-Area Cadmium-Sulfide Photoconductive Cells

RCA TYPES			Spectral Response	MAXIMUM RATINGS			CHARACTERISTICS AT 25° C				
Glass-Metal Types[a]	All-Glass Types[a]	Plastic-Filled Glass-Metal Types[b]		Voltage Between Terminals DC or Peak AC volts	Power Dissipation[c] watt	Photocurrent ma	Voltage Between Terminals volts	Illumination[d] foot-candles	Photocurrent[e] ma		Max. Decay Current[f] μa
									Min.	Max.	
SQ2525	SQ2500	SQ2532	S-15	250	0.2	20	12 (dc)	1	0.24	0.8	6
SQ2521	4423	SQ2532V1	S-15	250	0.2	20	50 (ac)	1[g]	1.5[h]	4[h]	40
SQ2526	SQ2523	SQ2532V2	S-15	110	0.2	50	12 (dc)	1	1	3	80
SQ2527	SQ2524	SQ2532V3	S-15	110	0.2	50	12 (dc)	1	2	6	80
SQ2520	4425	SQ2532V4	S-15	110	0.2	50	12 (dc)	1	3.6	14.5	80



4423, SQ2500 | SQ2521, SQ2525, SQ2532, SQ2532V1 | 4425, SQ2523, SQ2524 | SQ2520, SQ2526, SQ2527, SQ2532V2, SQ2532V3, SQ2532V4

a The maximum ambient operating temperature range for these cells is −75° C to +60° C.

b The maximum ambient operating temperature range for these cells is −40° C to +60° C.

c In continuous service with sensitive surface of cell fully illuminated. The power dissipation rating applies up to the maximum rated ambient operating temperature.

d For conditions where the light source is a tungsten-filament lamp operated at a color temperature of 2870° K.

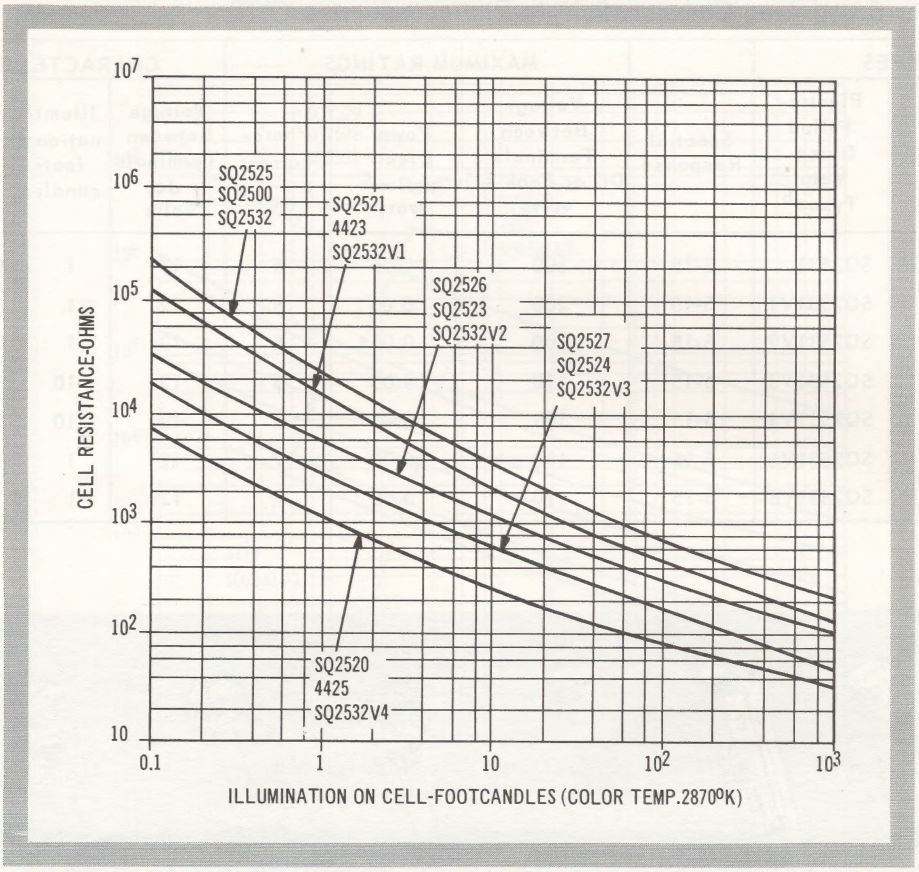
e This characteristic is determined after the cell has been exposed for a period of 16 to 24 hours to 50 to 100 footcandle illumination (white fluorescent light).

f Measured 10 seconds after removal of incident-illumination level.

g For conditions where light flux from a tungsten-filament lamp operated at 2870° K is transmitted through a filter (Corning C.S. No. 1-62 which has an effective transmission of luminous flux of 13.3%) onto the sensitive surface. The value of illumination incident on the sensitive surface is 7.5 footcandles measured before positioning the filter between the lamp and the cell. The sensitive surface of the cell is fully illuminated.

h This characteristic is determined after the cell has been exposed for a period of 16 to 24 hours to 500 footcandle illumination (white fluorescent light).

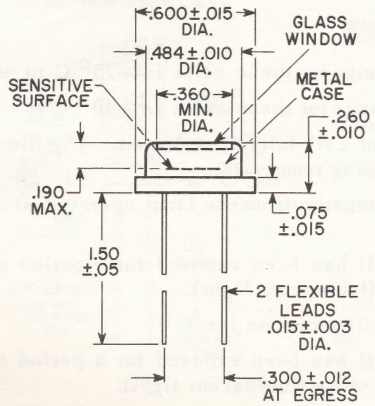
Illustrations show actual photocell size.



DC Cell Resistance of 1/2" – Diameter Broad-Area Photoconductive Cells as a Function of Cell Illumination

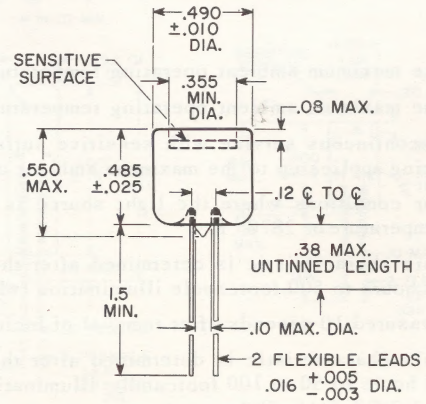
DIMENSIONS IN INCHES

GLASS-METAL TYPES
MODIFIED TO-8 CASE



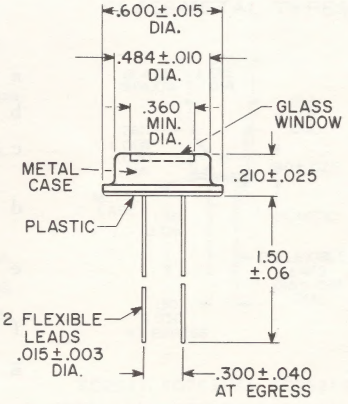
SQ2520, SQ2521, SQ2525, SQ2526, SQ2527

ALL-GLASS TYPES



4423, 4425, SQ2500, SQ2523, SQ2524

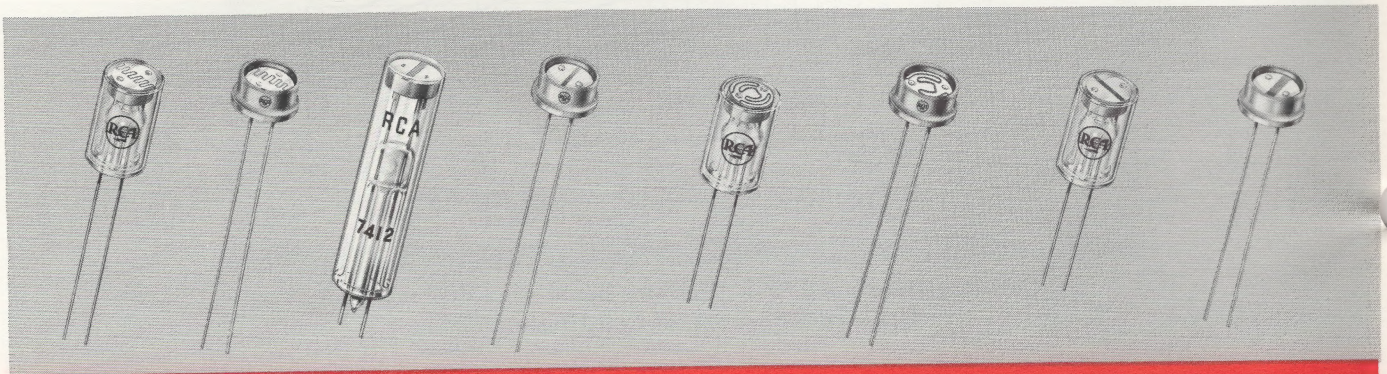
PLASTIC-FILLED GLASS-METAL TYPES



SQ2532, SQ2532V1, SQ2532V2, SQ2532V3, SQ2532V4

1/4"-Diameter Broad-Area Cadmium-Sulfide Photoconductive Cells

RCA TYPES			Spectral Response	MAXIMUM RATINGS			CHARACTERISTICS AT 25° C				
Glass-Metal Types[a]	All-Glass Types[a]	Plastic-Filled Glass-Metal Types[b]		Voltage Between Terminals DC or Peak AC volts	Power Dissipation[c] watt	Photocurrent ma	Voltage Between Terminals dc volts	Illumination[d] foot-candles	Photocurrent[e] ma		Max. Decay Current[f] μa
									Min.	Max.	
SQ2529	SQ2528	SQ2531	S-15	300	0.05	5	12	1	0.004	0.012	0.1
–	–	SQ2531V1	S-15	200	0.05	5	12	1	0.04	0.12	1
SQ2508	7412	SQ2531V2	S-15	200	0.05	5	12	1	0.065	0.275	1
–	4413	SQ2531V3	S-15	110	0.05	5	12	10	1.4	2.75	12
SQ2519	4402	SQ2531V4	S-15	300	0.05	5	12	10	1.6[g]	–	12
–	–	SQ2531V5	S-15	110	0.05	7	12	1	1	3	15
–	–	SQ2531V6	S-15	110	0.05	7	12	1	1.6	4.8	15



4413 SQ2531V3 7412 SQ2508 SQ2581V1 SQ2531V2 4402 SQ2519, SQ2531V4 SQ2531V5 SQ2531V6 SQ2528 SQ2529, SQ2531

a The maximum ambient operating temperature range for these cells is −75° C to +60° C.

b The maximum ambient operating temperature range for these cells is −40° C to +60° C.

c In continuous service with sensitive surface of cell fully illuminated. The dissipation rating applies up to the maximum ambient operating temperature.

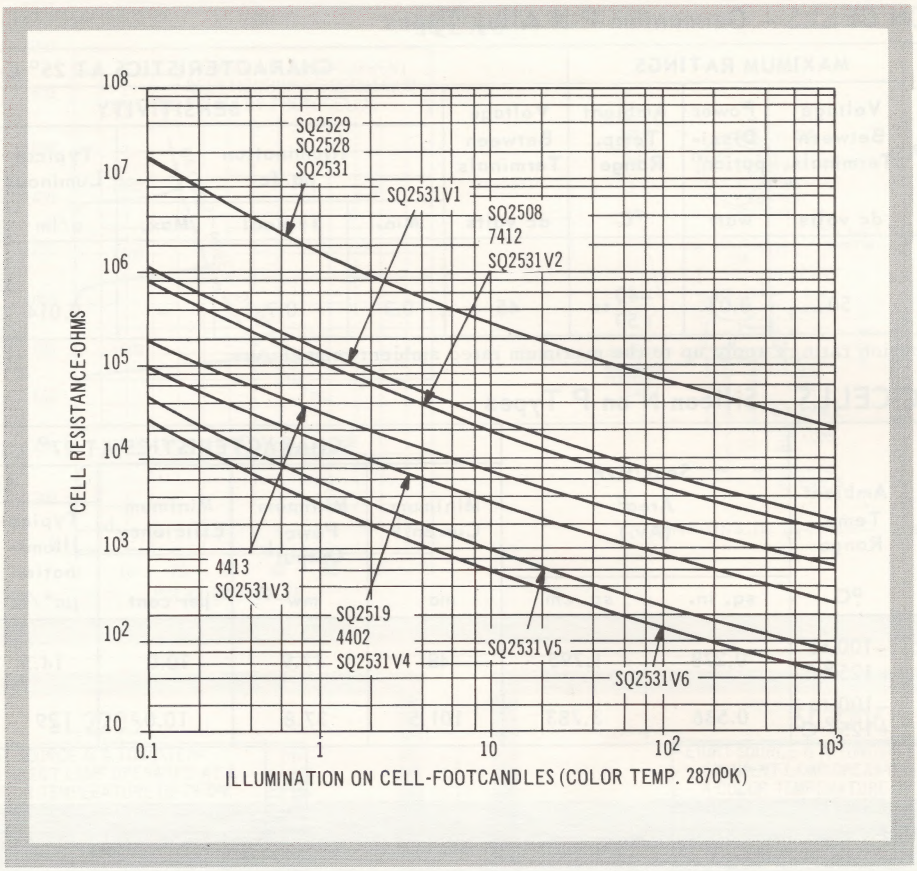
d For conditions where the light source is a tungsten-filament lamp operated at a color temperature of 2870° K.

e This characteristic is determined after the cell has been exposed for a period of 16 to 24 hours to 500 footcandle illumination (white fluorescent light).

f Measured 10 seconds after removal of incident-illumination level.

g This characteristic is determined after the cell has been exposed for a period of 16 to 24 hours to 50 to 100 footcandle illumination (white fluorescent light).

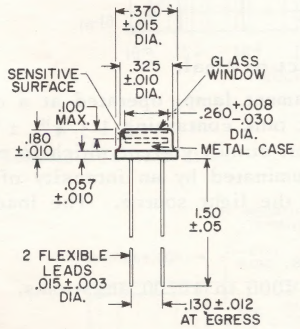
Illustrations show actual photocell size.



DC Cell Resistance of 1/4" – Diameter Broad-Area Photoconductive Cells as a Function of Cell Illumination

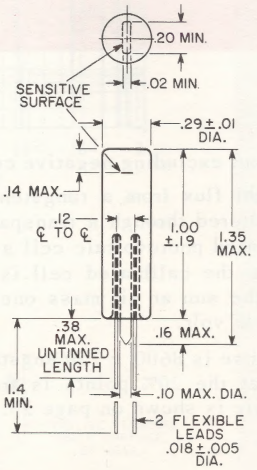
DIMENSIONS IN INCHES

GLASS-METAL TYPES
MODIFIED TO-5 CASE

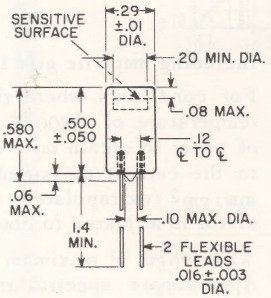


SQ2508, SQ2519, SQ2529

ALL-GLASS TYPES

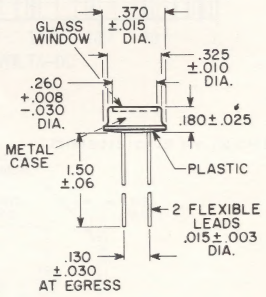


7412 ONLY



4402, 4413, SQ2528

PLASTIC-FILLED
GLASS-METAL TYPES



SQ2531, SQ2531V1, SQ2531V2, SQ2531V3, SQ2531V4, SQ2531V5, SQ2531V6

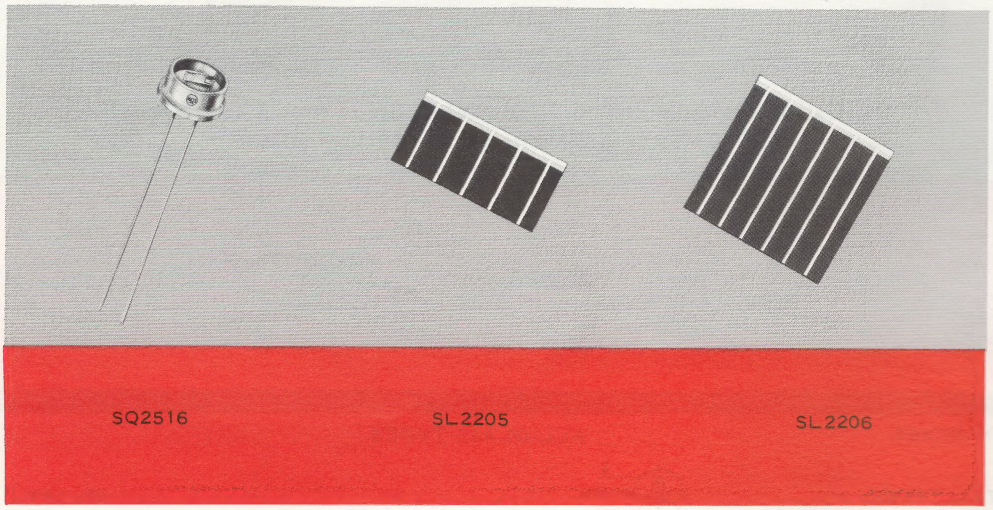
PHOTOJUNCTION CELLS – Germanium P-N Alloy Types

RCA Type	Spectral Response	MAXIMUM RATINGS			CHARACTERISTICS AT 25° C						
		Voltage Between Terminals	Power Dissipation[a]	Ambient Temp. Range	Voltage Between Terminals	SENSITIVITY					Max. Dark Current
						Illumination μa/fc			Typical Luminous	Typical Radiant at 6.5 microns	
		dc volts	watt	°C	dc volts	Min.	Typical	Max.	a/lm	a/w	μa
SQ2516	S-14	50	0.03	−40 to +50	45	0.3	0.7	–	0.014	0.52	35

a The power dissipation ratings apply up to the maximum rated ambient temperature.

PHOTOVOLTAIC CELLS – Silicon N on P Types

RCA Type	Spectral Response	Ambient Temp. Range	Sensitive Area[a] (Av.)		CHARACTERISTICS AT 27° ± 1° C					
					Minimum Current[b]	Minimum Power Output[b]	Minimum Efficiency[b]	SENSITIVITY		
								Typical Illumination	Typical Luminous	Typical Radiant at 8600 Å
		°C	sq. in.	sq. cm	ma	mw	per cent	μa*/fc	ma*/lm	a*/w
SL2205	(c)	−100 to +125° C	0.278	1.795	48	17.9	10.0	14.5	7.13	0.58
SL2206	(c)	−100 to +125° C	0.586	3.783	101.5	37.8	10.0	29	7.13	0.58



a Including metallic grid lines but excluding negative contact terminal.

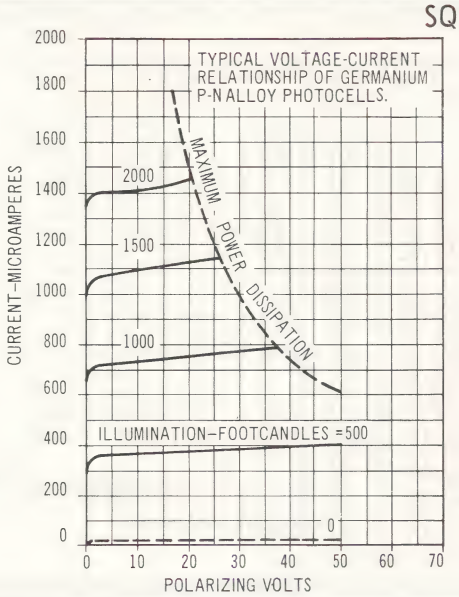
b For conditions where the light flux from a tungsten-filament lamp, operated at a color temperature of 2800°K, is filtered through a transparent tank containing 1-3/4" ± 1/8" of water to obtain on a calibrated photovoltaic cell a short-circuit current which is equal to the current measured when the calibrated cell is illuminated by an intensity of 100 mw/cm2 (extrapolated) with the sun at air mass one as the light source. The load resistor is adjusted to obtain 0.46 volt.

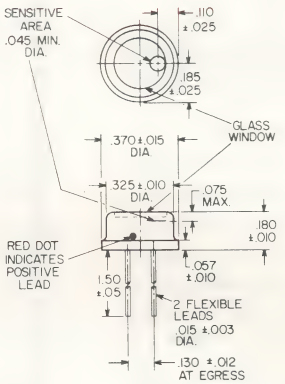
c Wavelength of maximum response is 8600 ± 750 angstroms. Approximate spectral range at the 20% points is from 4000 to 10700 angstroms. The spectral response characteristic is shown on page 23.

* Short-circuit current.

Illustrations show actual photocell size.

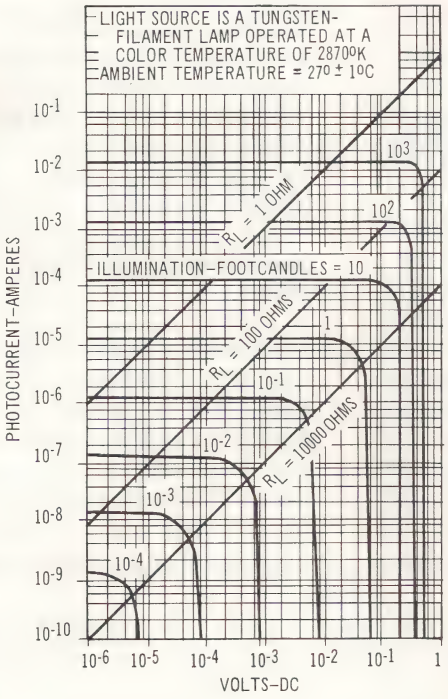
SQ2516



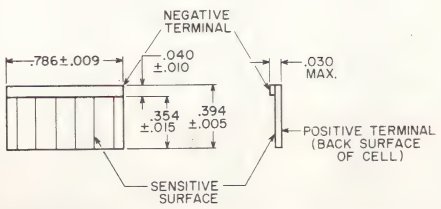


DIMENSIONS IN INCHES

SL2205


LIGHT SOURCE IS A TUNGSTEN-FILAMENT LAMP OPERATED AT A COLOR TEMPERATURE OF 2870°K
AMBIENT TEMPERATURE = 27° ± 1°C
ILLUMINATION–FOOTCANDLES = 10
RL = 1 OHM
RL = 100 OHMS
RL = 10000 OHMS
PHOTOCURRENT–AMPERES
VOLTS–DC

DIMENSIONS IN INCHES



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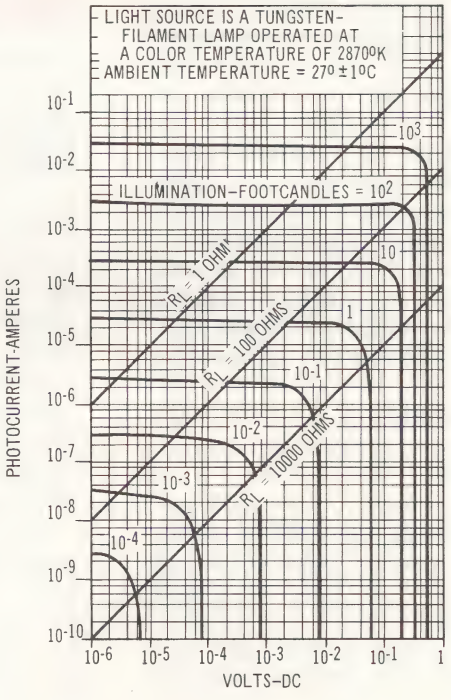
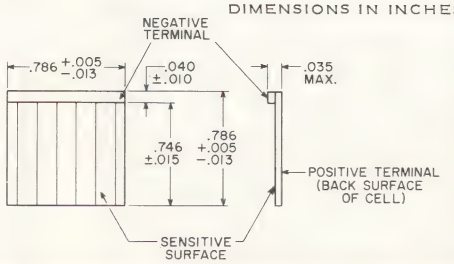

LIGHT SOURCE IS A TUNGSTEN-FILAMENT LAMP OPERATED AT A COLOR TEMPERATURE OF 2870°K
AMBIENT TEMPERATURE = 27° ± 1°C
ILLUMINATION–FOOTCANDLES = 10²
RL = 1 OHM
RL = 100 OHMS
RL = 10000 OHMS
PHOTOCURRENT–AMPERES
VOLTS–DC

DIMENSIONS IN INCHES



PHOTOELECTRIC MEASUREMENTS

LIGHT

Historically, photoelectric measurements and specifications have been related to the measurement of illumination. It is appropriate, therefore, to consider the characteristics of the eye and related photometric units. Although characteristics of the human eye vary from person to person, **standard luminosity coefficients** for the eye were defined by the Commission Internationale de Eclairage (International Commission on Illumination) in 1931. These standard C.I.E. luminosity coefficients are listed in Table I. They represent the relative luminous equivalents of an equal-energy spectrum for each wavelength in the visible range, assuming foveal vision. An absolute "sensitivity" figure established for the standard eye relates photometric units and radiant power units. At 5550 angstroms, the wavelength of maximum sensitivity of the eye, one watt of radiant power corresponds to 680 lumens. The visibility characteristic of the human eye is shown in Fig. 1.

Photometry deals with the measurement of light in reference to the effect produced on the theoretical standard C.I.E. observer. Measurements are made by visual comparison or by some equivalent photoelectric method. Units, standards, and systems of measurement have been developed to correspond to the effect as observed by the eye.

Luminous intensity (or **candlepower**) is a measure of a light source which describes its luminous flux per unit solid angle in a particular direction. For many years the standard measure of luminous intensity was the international candle established by a group of carbon-filament lamps at the Bureau of Standards. In 1948 the International Commission on

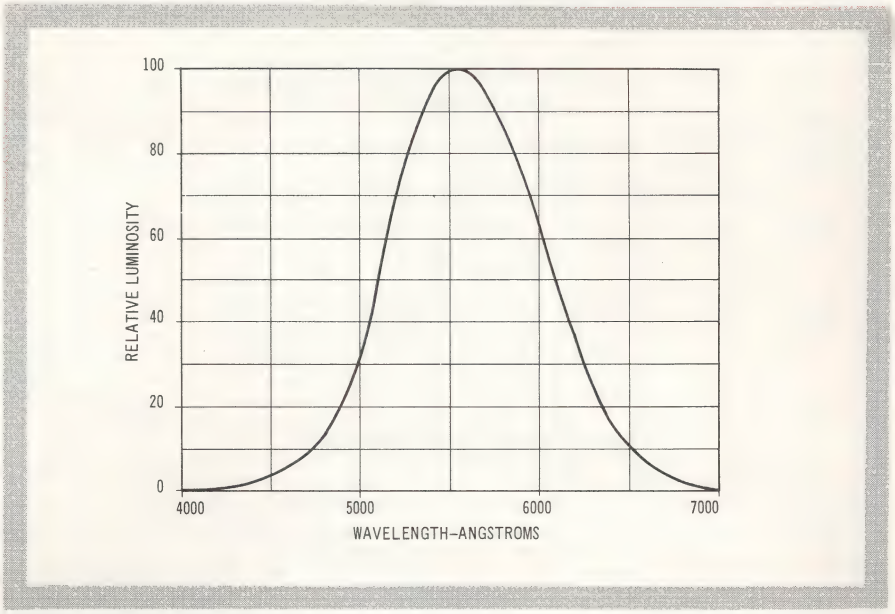


Fig. 1. - Visibility Characteristic of Human Eye.

Illumination agreed on the introduction of a new standard of luminous intensity and recommended the adoption of the name **candela** to distinguish it from the international candle. The term candela is now widely used abroad and is coming into general use in the United States; the older term **candle** is sometimes still used, but refers to the new candle or candela.

The candela is defined by the radiation from a black body at the temperature of solidification of platinum. A candela is one-sixtieth of the luminous intensity of one square centimeter of such a radiator. The major advantage of the new standard is that it may be reproduced in any laboratory. The effective change in the value of the candle as a result of the 1948 agreement is of the order of tenths of one per cent and, therefore, is negligible in practical measurements.

Luminous flux is the time rate of flow of light energy—that characteristic of radiant energy which produces visual sensation. The unit of luminous flux is the lumen, which is the flux emitted in unit

TABLE I

STANDARD (C.I.E.) SPECTRAL LUMINOUS-EFFICIENCY VALUES (RELATIVE TO UNITY AT 555 MILLIMICRONS WAVELENGTH). THESE VALUES REPRESENT THE RELATIVE CAPACITY OF RADIANT ENERGY OF VARIOUS WAVELENGTHS TO PRODUCE VISUAL SENSATIONS. [a]

WAVELENGTH (ANGSTROMS)	C.I.E. VALUE	WAVELENGTH (ANGSTROMS)	C.I.E. VALUE	WAVELENGTH (ANGSTROMS)	C.I.E. VALUE
3800	0.00004	5100	0.503	6400	0.175
3900	0.00012	5200	0.710	6500	0.107
4000	0.0004	5300	0.862	6600	0.061
4100	0.0012	5400	0.954	6700	0.032
4200	0.0040	5500	0.995	6800	0.017
4300	0.0116	5600	0.995	6900	0.0082
4400	0.023	5700	0.952	7000	0.0041
4500	0.038	5800	0.870	7100	0.0021
4600	0.060	5900	0.757	7200	0.00105
4700	0.091	6000	0.631	7300	0.00052
4800	0.139	6100	0.503	7400	0.00025
4900	0.208	6200	0.381	7500	0.00012
5000	0.323	6300	0.265	7600	0.00006

solid angle by a uniform point source of one candela. Such a source produces a total luminous flux of 4π lumens.

A radiant source may be evaluated in terms of luminous flux if the radiant-energy distribution of the source is known. If $W(\lambda)$ is the total radiant power in watts per unit wavelength, total radiant power over all wavelengths is $\int_0^\infty W(\lambda)\,d\lambda$, and the total luminous flux L in lumens can be expressed as follows:

$$L = \int_0^\infty [680\ W(\lambda)]\,[y(\lambda)]\,d\lambda \qquad (1)$$

where $y(\lambda)$ represents the luminosity coefficient (Table I) as a function of wavelength.

Illumination is the density of luminous flux incident on a surface. A common unit of illumination is the **footcandle**, which is the illumination produced by one lumen uniformly distributed over an area of one square foot. It follows that a source of one candela produces an illumination of one footcandle at a distance of one foot.

Table II lists some common values of illumination encountered in photoelectric applications.

A practical advantage of using luminous standards for testing photoelectric devices is that the test standard usually is a tungsten lamp calibrated for color temperature and luminous intensity. Secondary standards can readily be prepared by photometric comparison.

A suitable substandard for practical photoelectric measurements is the developmental-type calibrated lamp, RCA Dev. No. C70048, which operates at a current of about 4.5 amperes and a voltage of 7 to 10 volts. A typical lamp calibrated at a color temperature of 2870 degrees Kelvin provides a luminous intensity of 55 candelas. The luminous intensity of a tungsten lamp measured in candelas is usually numerically somewhat greater than the power delivered to the lamp in watts.

Because the spectral emission of the tungsten lamp is known, the radiant sensitivity of a photodevice can be calculated by rather simple procedures if the relative spectral-response characteristic of the device is known.[b]

RADIANT ENERGY

Black-body radiation.[c] As a body is raised in temperature, it first emits radiation primarily in the invisible infrared region; then, as the temperature is increased, the radiation shifts to the shorter wavelengths in the visible spectrum. If the radiating body is one which may be described technically as "black", its behavior may be accurately described by the laws of radiation. Because the black-body radiation is used as a standard for the infrared region and because other sources may be described in terms of the black body, a brief review of black-body radiation laws and standards is given below.

A black body is one which absorbs all incident radiation; none is transmitted and none is reflected. Because, in thermal equilibrium, thermal radiation balances absorption, it follows that a black body is the most efficient thermal radiator possible. A black body radiates more total power and more power at a particular wavelength than any other thermally radiating source at the same temperature. There are two general theoretical laws which describe the radiation from a black body.

The Stefan-Boltzmann law describes the total radiant flux W per unit area from a black body as a function of temperature, as follows:

$$W = \sigma T^4 \qquad (2)$$

where σ is equal to 5.6819×10^{-12} watt per square centimeter per degree^4, and T is the temperature of the radiator in degrees Kelvin.

Planck's radiation law describes the spectral distribution of black-body radiation as follows:

$$J_\lambda = C_1 \lambda^{-5} (e^{C_2/\lambda T} - 1)^{-1} \qquad (3)$$

where J_λ is the power in watts in the complete solid angle of 2π steradians on one side of the black-body plane (Lambert's cosine law applying) per unit area for an increment of wavelength of one centimeter; C_1 is equal to 3.7413×10^{-12} square centimeter-watts (the first radiation constant); λ is the wavelength in centimeters; and C_2 is equal to 1.4380 centimeter-degree (the second radiation constant). Fig. 2 illustrates the distribution of black-body radiant energy as a function of wavelength for a number of different temperatures as calculated from Eq. (3).

Although no material is ideally black, the equivalent of a theore-

TABLE II

TYPICAL VALUES OF ILLUMINATION FOR VARIOUS CONDITIONS

CONDITION	ILLUMINATION (FOOTCANDLES)
SOLAR ILLUMINATION (OUTSIDE OF ATMOSPHERE)	12700
AVERAGE SOLAR ILLUMINATION, 42° N LATITUDE NOON, JUNE 21, MEASURED IN A PLANE PERPENDICULAR TO THE SUN'S RAYS	8800
RECOMMENDED FOR READING	30 to 70
MOONLIGHT	0.02
NATURAL NIGHT ILLUMINATION, CLEAR, NO MOON.*	9×10^{-5}
NATURAL NIGHT ILLUMINATION, HEAVILY CLOUDY, NO MOON.	2×10^{-5}

* ALTHOUGH PUBLISHED DATA ARE IN SOME DISAGREEMENT, IT APPEARS THAT STARLIGHT ITSELF IS A SUBSTANTIAL BUT NOT A MAJOR COMPONENT OF THE QUOTED FIGURE. NOTE ALSO THAT ZODIACAL RADIATION IN THE NEAR-INFRARED IS MANY ORDERS OF MAGNITUDE HIGHER THAN IN THE VISIBLE REGION.

tical black body can be achieved in the laboratory by providing a hollow radiator with a small exit hole. The radiation from the hole approaches that of a theoretical black radiator if the area of the cavity is large compared with the area of the exit hole. The characteristic of 100-per-cent absorption is achieved because any radiation entering the hole is reflected many times inside the cavity. For many years experimental physicists had to build their own black-body radiators; however, well-designed commercial radiators are now available.

For a radiation source which is not black, the radiation may be calculated from black-body radiation laws provided the emissivity as a function of wavelength is known. Spectral emissivity e_λ is defined as the ratio of the output of a radiator at a specific wavelength to that of a black body at the same temperature. Tungsten sources, for which tables of emissivity data are available[d], are widely used as practical standards, particularly for the visible range. Tungsten radiation standards for the visible range are frequently given in terms of color temperature, instead of true temperature. The color temperature of a selective radiator is determined by comparison with the true temperature of a black body; when the output of the selective radiator is the closest possible approximation of a perfect color match in the range of the visual sensitivity, the color temperature is numerically the same as the black-body temperature. For a tungsten source, the relative distribution of radiant energy in the visible spectral range is very close to that of a black body although the absolute temperatures differ. However, the match of energy distribution becomes progressively worse in the ultraviolet and infrared spectral regions.

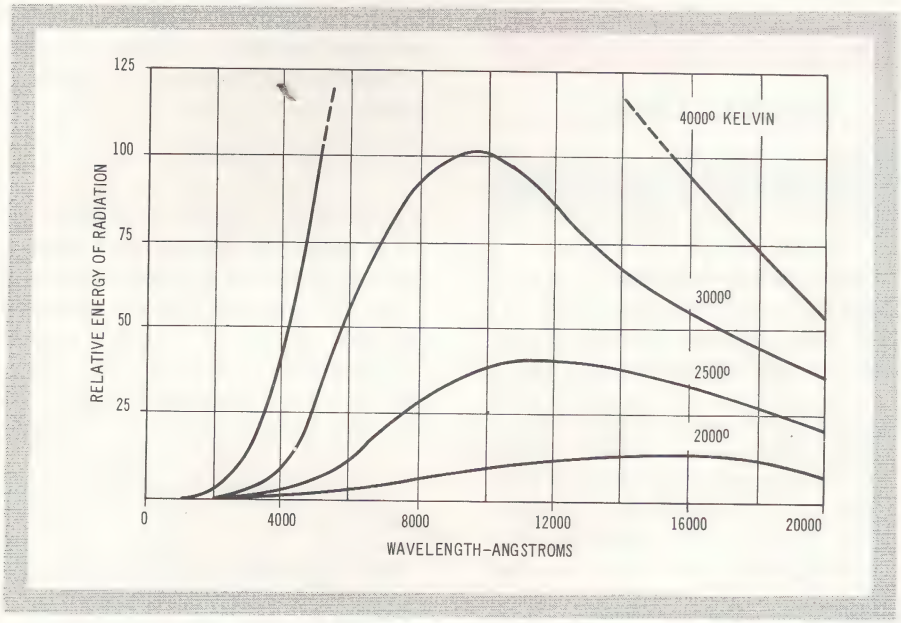


Fig. 2. - Distribution of Black-Body Radiant Energy as a Function of Wavelength at Various Temperatures.

Radiation sources and characteristics. Relative spectral-emission characteristics for some of the most important radiation sources are shown in Fig. 3.

Tungsten lamps are probably the most important type of radiation source for photoelectric applications because of their availability, reliability, and constancy of operating characteristics.

The common fluorescent lamp, which is a very efficient light source, consists of an argon-mercury glow discharge in a bulb internally coated with a phosphor that converts ultraviolet radiation from the discharge into useful light output. There are numerous types of fluorescent lamps having different output spectral distribution depending upon the phosphor and gas-filling. The spectral response shown in Fig.3 is a typical curve for a fluorescent lamp of the "daylight" type.

A very useful point source is the zirconium concentrated-arc lamp. Concentrated-arc lamps are available having ratings from 2 to 300 watts, and in "point" diameters from 0.003 to 0.116 inch. Operation of these lamps requires one special circuit to provide a high starting voltage and another well-filtered and ballasted circuit for operation.

Although many types of electrical discharge have been used as radiation sources, probably the most important is the mercury arc.

The character of the light emitted from the mercury arc varies with pressure and operating conditions. At increasing pressures, the spectral-energy distribution from the arc changes from the typical mercury-line spectra characteristic to an almost continuous spectrum of high intensity in the near-infrared, visible, and ultraviolet regions. Fig.3 includes the spectral-energy distribution from a water-cooled mercury arc at a pressure of 130 atmospheres.

Illumination of the north sky as a function of time near sunset as shown in Fig.4.

Fig.5 shows the transmission characteristics of a number of useful filters and radiation transmitting substances. Color filters are frequently used to isolate various regions of the spectrum to improve detection or matching characteristics of photodetectors. The transmission of various glasses and the atmosphere are also provided because these factors have an important influence on practical optical systems.

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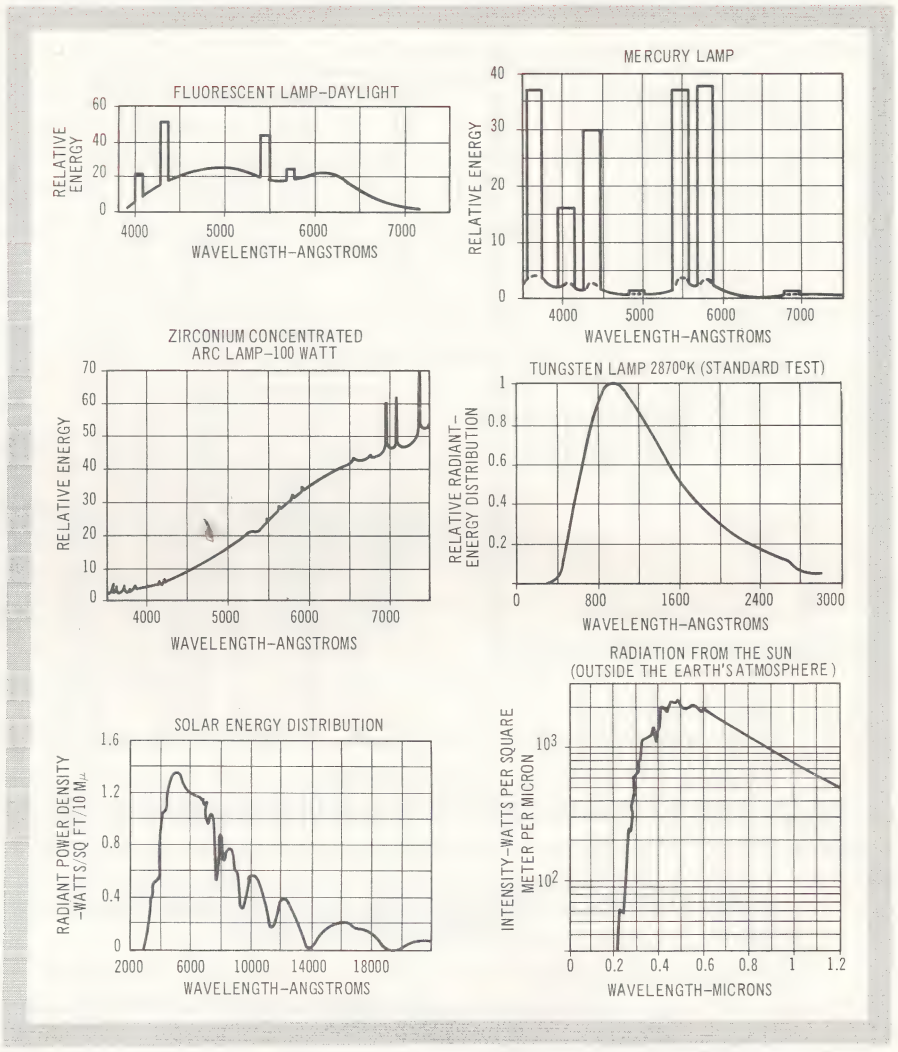


Fig. 3. - Relative Spectral-Emission Characteristics for Several Representative Radiation Sources.

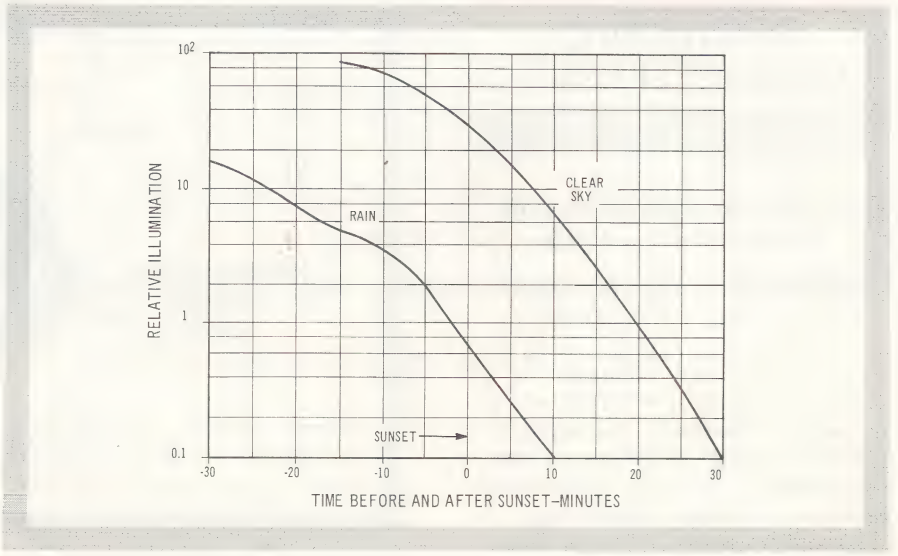


Fig. 4. - Illumination of the North Sky as a Function of Time near Sunset.

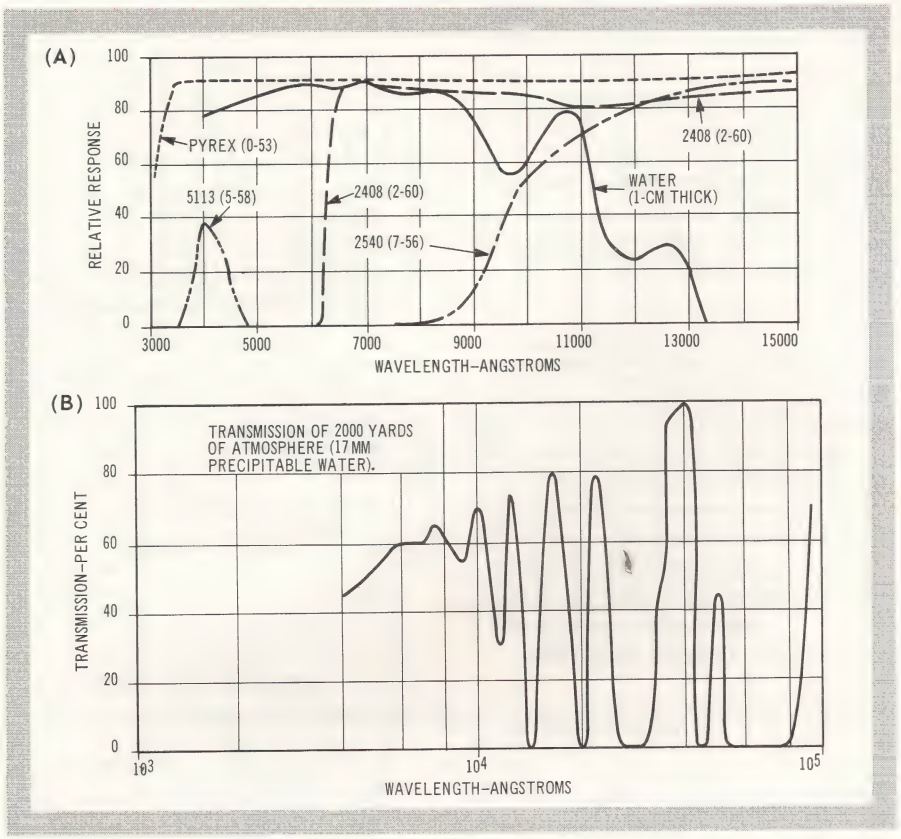


Fig. 5. - Transmission Characteristics of Various useful Color Filters, Glasses, and the Atmosphere. ((A) Corning Nos. 2540, 5113, 2408, Pyrex, or equivalent, and water (1-cm thick) (B) 2000 yds. of air.)

PHOTOCELL CHARACTERISTICS

Broad-Area Cadmium-Sulfide Photoconductive Cells

PHOTORESISTORS OR LIGHT-DEPENDENT RESISTORS

The essential elements of a cadmium-sulfide photocell are a ceramic substrate, a layer of photoconductive cadmium sulfide, electrodes, and a protective moisture-resistant enclosure. A cutaway view of a typical glass-metal photoconductive cell is shown in Fig.6.

The cadmium sulfide is treated (doped) with various activating materials, such as a chloride and copper, for increased sensitivity. The electrodes are formed by evaporation of a metal through a mask. Tin, indium, gold, and platinum are commonly used electrode metals although the latter two result in non-ohmic contracts, i.e., rectifying contracts between the electrode metal and the cadmium sulfide. For applications in which the cell is exposed to high humidity and high temperature for long periods of time, the envelope should be sealed hermetically. All-glass and glass-metal photocell types are hermetically sealed. In recent years, the resistance to moisture of some plastics has been improved and photocells encapsulated in these plastics are satisfactory for many applications.

Cadmium-sulfide photoconductive cells having ohmic contacts behave in a circuit as an ohmic impedance. One of the most important parameters of the photocell is its resistance at different levels of illumination. DC cell resistance as a function of cell illumination for some typical RCA photoconductive cells is shown in Fig. 7. It will be noted that the slope of the curves varies slowly and is nearly constant about any given operating point. Resistance may be expressed as

$$R_1 L^{-\gamma}$$

where R_1 is the resistance of the cell in ohms per unit illumination

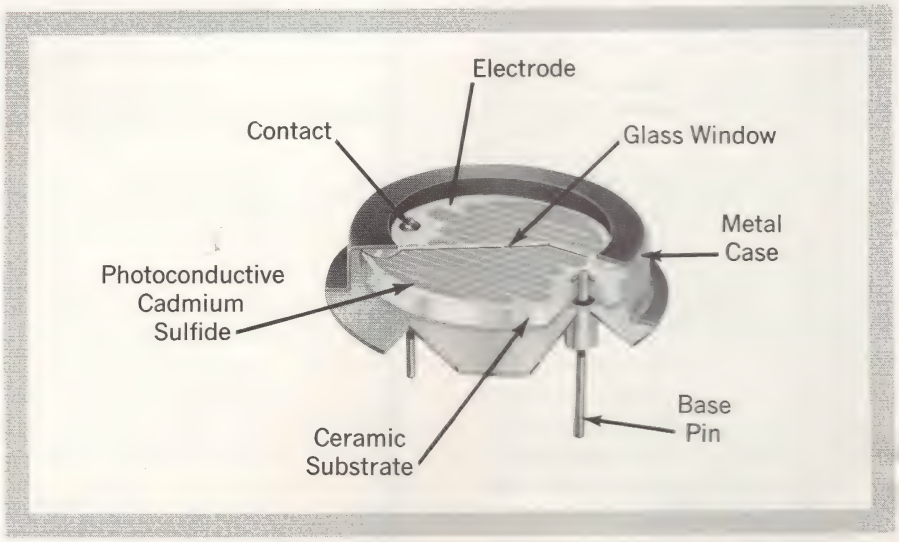


Fig. 6 - Cutaway View of a Typical Cadmium-Sulfide Photoconductive Cell.

L is the illumination in footcandles, and

γ is the slope of the characteristic at a given operating point

The performance of a photocell at a given operating point is described by specifying R_1 and γ. For a typical cell, the 7163, R_1 and γ are 0.019 x 10^6 ohms and 1, respectively (at 1 footcandle). The resistance or conductance of the cell is often indirectly expressed in terms of the current drawn through the cell at a given voltage and given light level.

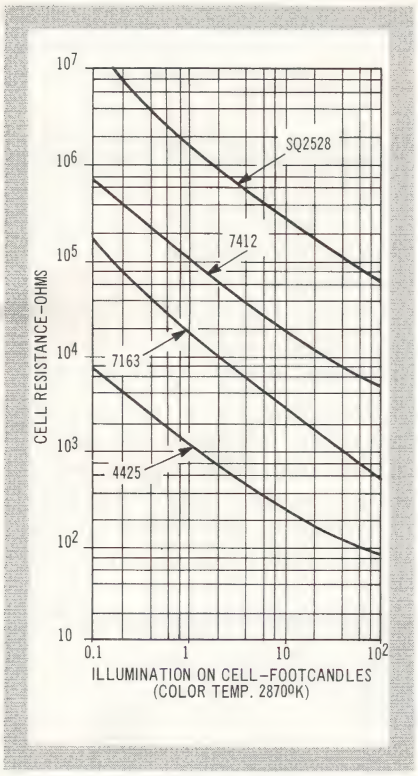


Fig. 7 - DC Cell Resistance as a Function of Cell Illumination for Typical RCA Photoconductive Cells.

The conductance (1/resistance) of this type of cell does not change rapidly with changes in incident illumination but requires some time to reach its steady-state value. This effect results from the presence of electron traps within the forbidden region of the band gap of the cadmium sulfide. Although the build-up and decay of conductance and current upon the application or removal of illumination is only approximately exponential, the term "time constant" is frequently used to describe the time required for conductance or current to reach 63.2% (rise) or 36.8% (fall) of its maximum value. If a photoconductive cell has been stored in the dark for a long period of time and is suddenly illuminated with 10 footcandles of illumination, its time constant is approximately 70 milliseconds. The time constant depends on the intensity of the applied illumination. In general, the cell responds more quickly to high illumination light levels than to low light levels and its rise time is usually longer than its decay time. Photocurrent rise curves are shown in Fig.8 and Fig.9.

In addition to these time effects, there are other time-associated phenomena that take place more slowly. These phenomena can best be described by saying that the cell has some memory of previous light exposure. Long exposure to high light levels tends to make the cell slightly less sensitive and somewhat faster in response regardless of whether or not voltage is applied to the cell during exposure. These changes are reversible, and the cell will revert to its former condition after a storage period in the dark.

Because of the "memory" of

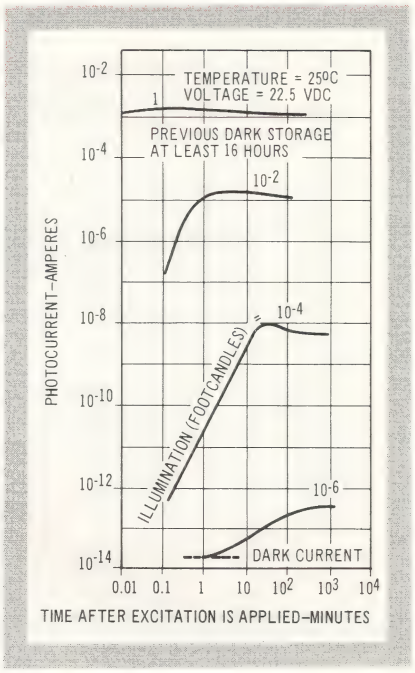


Fig. 9 - Rise Characteristics of a Cadmium-Sulfide Cell Selected for Low Dark Current.

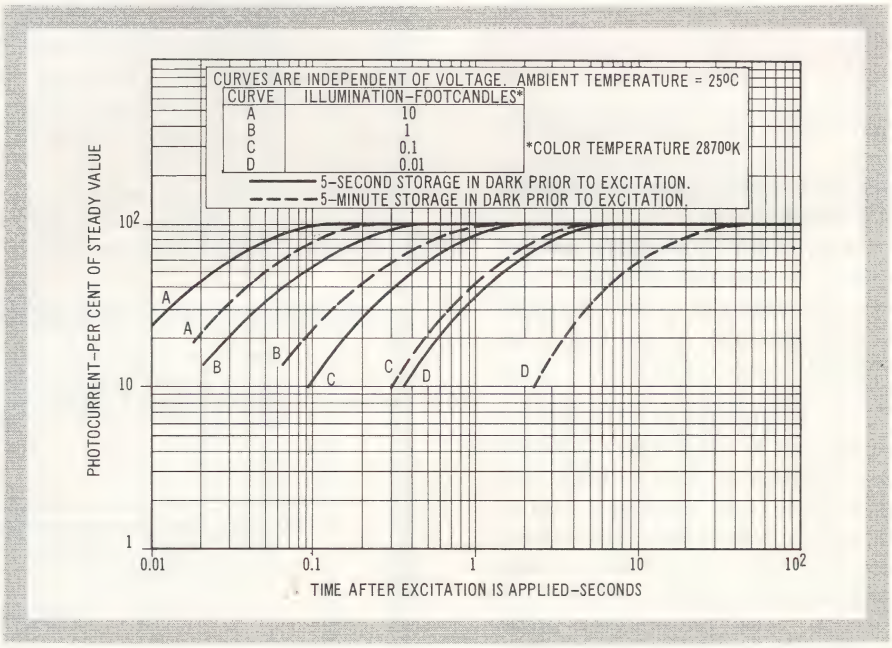

CURVES ARE INDEPENDENT OF VOLTAGE. AMBIENT TEMPERATURE = 25°C
CURVE ILLUMINATION–FOOTCANDLES*
A 10
B 1
C 0.1
D 0.01
*COLOR TEMPERATURE 2870°K
5–SECOND STORAGE IN DARK PRIOR TO EXCITATION.
5–MINUTE STORAGE IN DARK PRIOR TO EXCITATION.
PHOTOCURRENT–PER CENT OF STEADY VALUE
TIME AFTER EXCITATION IS APPLIED–SECONDS

Fig. 8 - Typical Rise Characteristics of a Cadmium-Sulfide Cell.

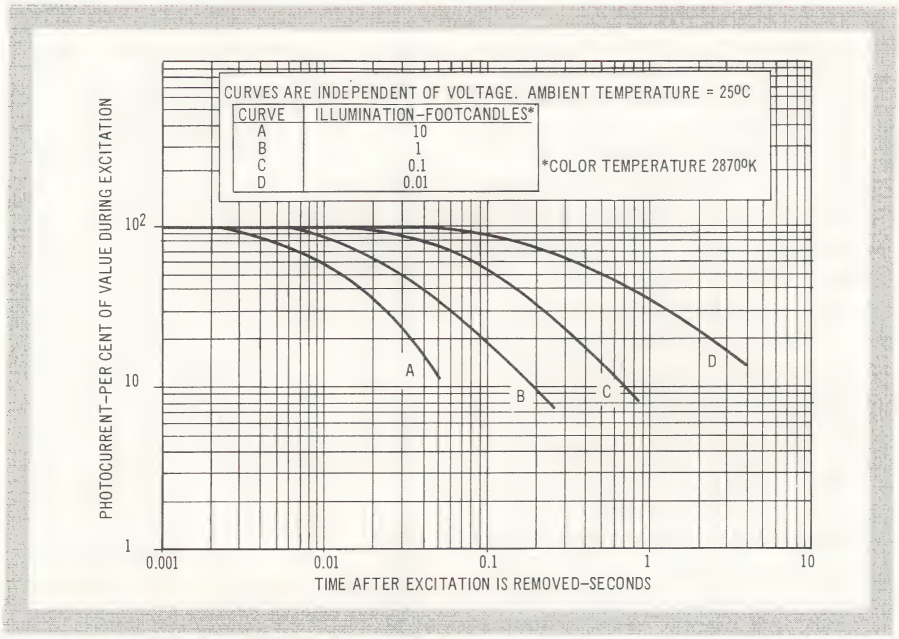


Fig. 10 - Typical Decay Characteristics of a Cadmium-Sulfide Cell.

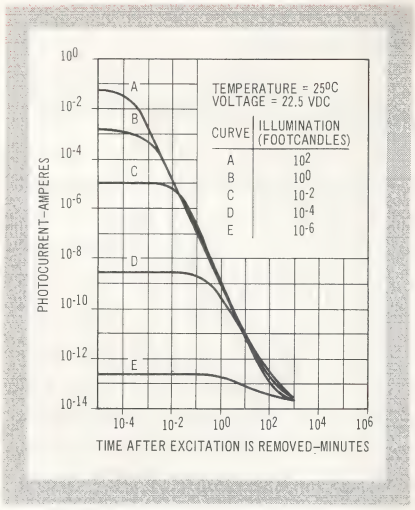


Fig. 11 - Decay Characteristics of a Cadmium-Sulfide Cell Selected for Low Dark Current.

the photocell, it is desirable to "light-precondition" a cell before a measurement of photocurrent is made. A commonly used preconditioning schedule employed in production testing is the exposure of the cell for 16 to 24 hours to 500 footcandles of fluorescent light. Voltage is not applied to the cell during the preconditioning schedule.

There are also time effects related to the application of voltage. For example, a cell is slightly less sensitive under ac voltage operation than under dc voltage operation.

In most photocell applications, it is important that the conductance of the cell be substantially less when the cell is in the dark than when it is illuminated. The terms dark current and decay current are used to describe cell performance under un-illuminated conditions. Dark current is that current which passes through the cell under specified conditions of voltage and temperature after the cell has been in the dark for a long period of time. Dark current usually has a very low value. Because of the time effects, it is more convient to specify the decay current which is observed at a given time interval following the removal of a given level of illumination. For the 7163 at an applied voltage of 50 volts, decay current is below 40 μa, 10 seconds after the removal of 1 footcandle of illumination. Photocurrent decay curves are shown in Fig.10 and Fig.11.

Peak-to-valley response as a function of square-wave light input for a typical cell is shown in Fig.12. As expected, the frequency response is higher for higher levels of illumination.

A typical family of curves showing photocurrent as a function of applied voltage at different levels of illumination is shown in Fig.13. Linearity extends over six orders of magnitude.

The sensitivity of the cell tends to decrease as ambient temperature rises; typical curves are shown in Fig.14. The effect is marked at low levels of illumination but tends to become in-

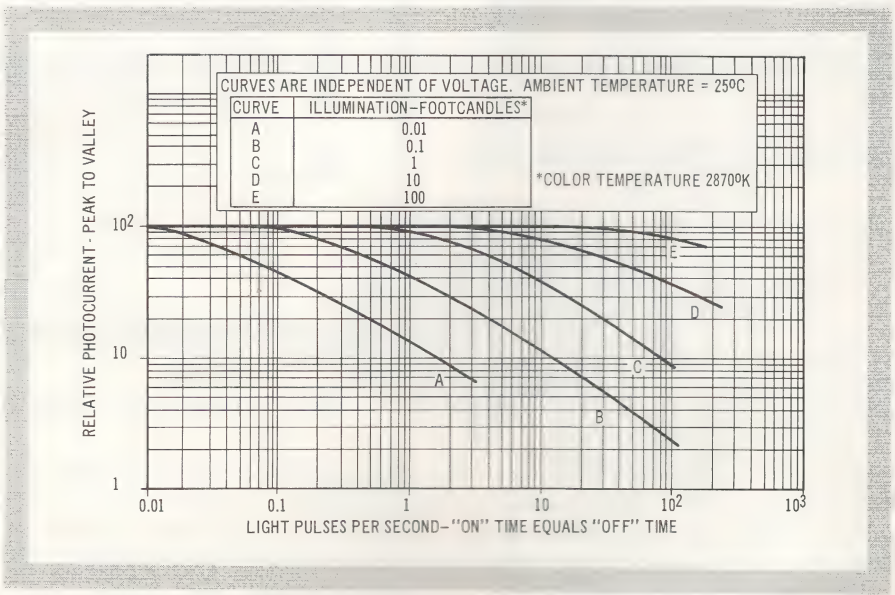


Fig. 12 - Response Characteristics of a Cadmium-Sulfide Cell to Pulsed Light.

significant at 10 footcandles and higher.

The sensitivity of the photocell is also dependent on the wavelength of incident illumination, as shown in Fig. 15. The response curve, which is centered well within the visible spectrum, has a peak of sensitivity near 5800 angstroms. Because the spectral response of cadmium-sulfide photocells closely matches the response of the human eye, these cells are especially useful for applications in which human vision is a factor. Examples of such applications are automatic street-light control, automatic yard-light control, and automatic iris-control in photographic cameras.

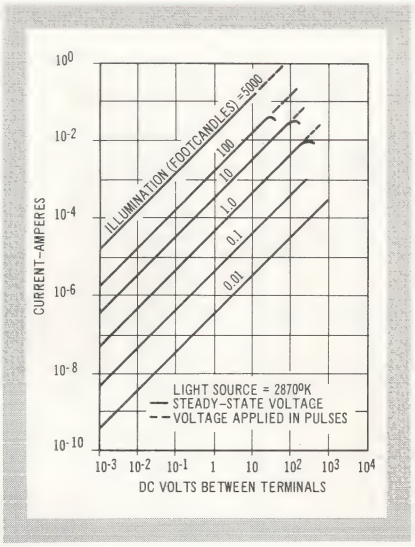


Fig. 13 - Current Versus Voltage Characteristics of a Cadmium-Sulfide Cell.

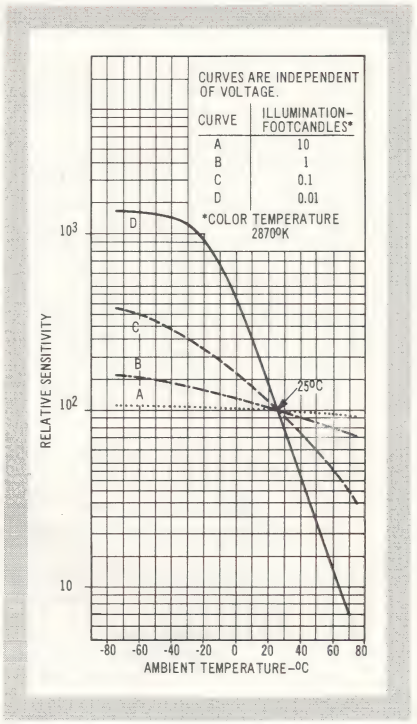


Fig. 14 - Typical Characteristics of a Cadmium-Sulfide Cell.

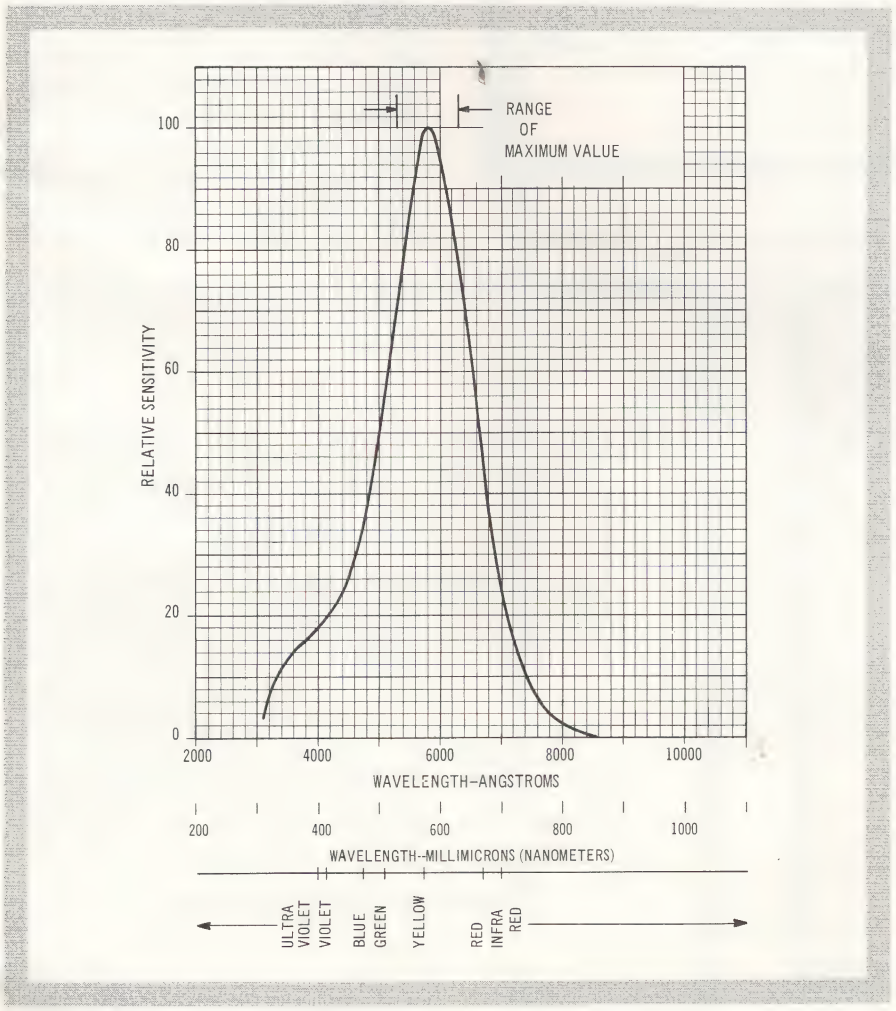


Fig. 15 - Spectral Sensitivity Characteristic for Cadmium-Sulfide Cell which has S-15 Response. Curve is shown for Equal Values of Radiant Flux at all Wavelengths.

PHOTOJUNCTION CELLS

As mentioned previously, both germanium and silicon are photoconductive and are used in the manufacture of junction photocells. In the processing of this type of cell, a p-n junction is formed in the material, which causes it to exhibit a non-ohmic (rectifying) characteristic, as shown in Fig. 16. The solid curve applies when the cell is in the dark; when light is applied to the cell, the curve shifts downward.

The junction photocell is customarily used as either a photoconductive device or as a photovoltaic device. In photoconductive applications, the cell is reverse biased and the output voltage is developed across a series load resistor. In photovoltaic applications, the cell is used to convert radiant power directly into electrical power.

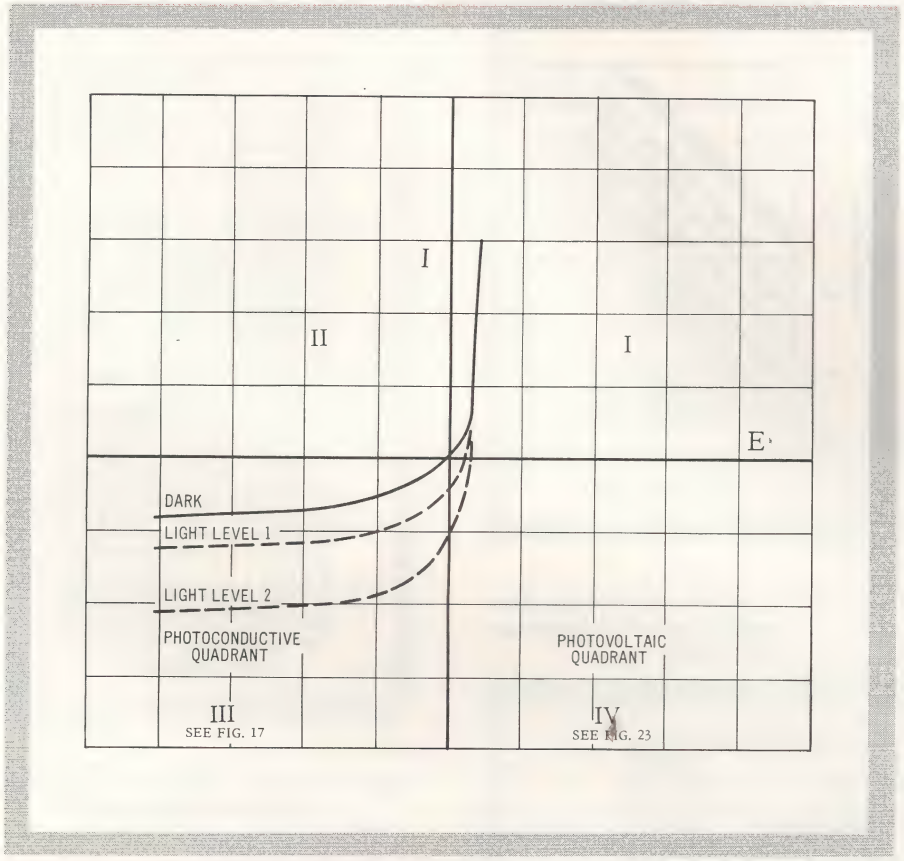


Fig. 16 - Current Versus Voltage Characteristics for a Junction Photodevice.

GERMANIUM P-N ALLOY PHOTOCELLS

When the photojunction cell is operated in the photoconductive mode, (quadrant III) the characteristic of Fig.16 is rotated by 180° and appears as shown in Fig.17. A load line has been drawn for a supply voltage of 45 volts and a load resistor of 50 kilohms. If the illumination on the cell is increased from 0 to 500 foot-candles, the change in voltage developed across the load resistor is ΔV.

The load resistor must be selected to have a value low enough to prevent "clipping" of the output signal due to increase in dark current at the maximum operating temperature of the system. Dark current increases with increasing temperature. A curve showing dark current as a function of temperature is shown in Fig.18.

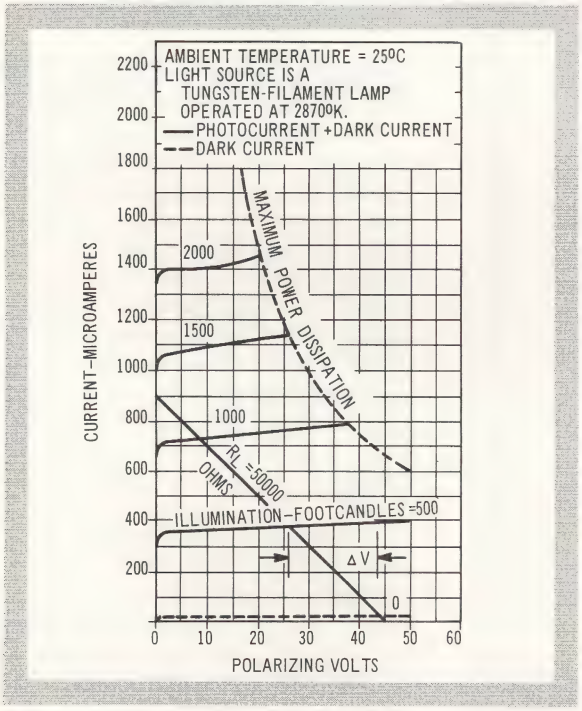


Fig. 17 - Typical Characteristics of Germanium p-n Alloy Photojunction Cells. Operation is in Quadrant III of Fig. 16.

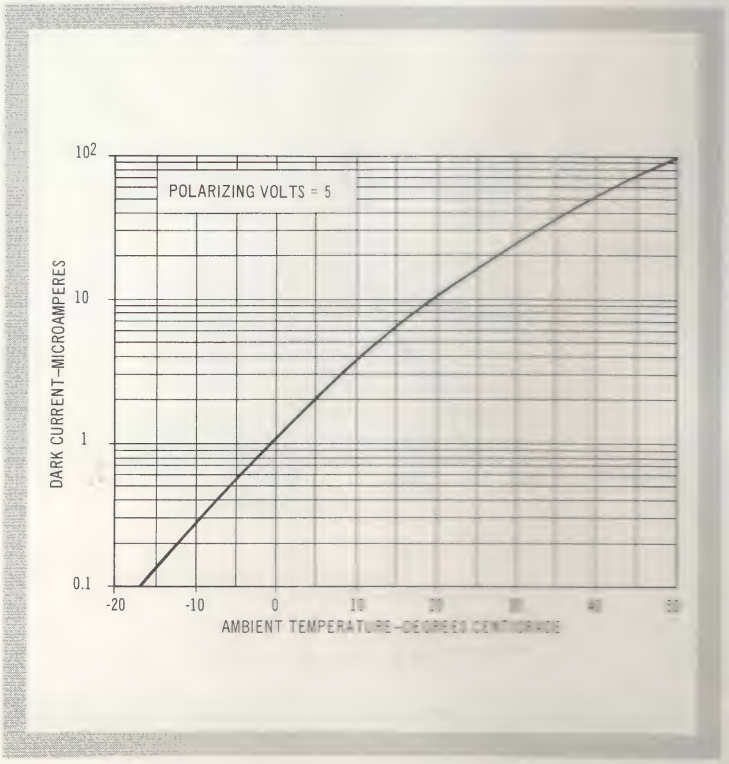


Fig. 18 - Typical Dark-Current Characteristic of Germanium p-n Alloy Photojunction Cells.

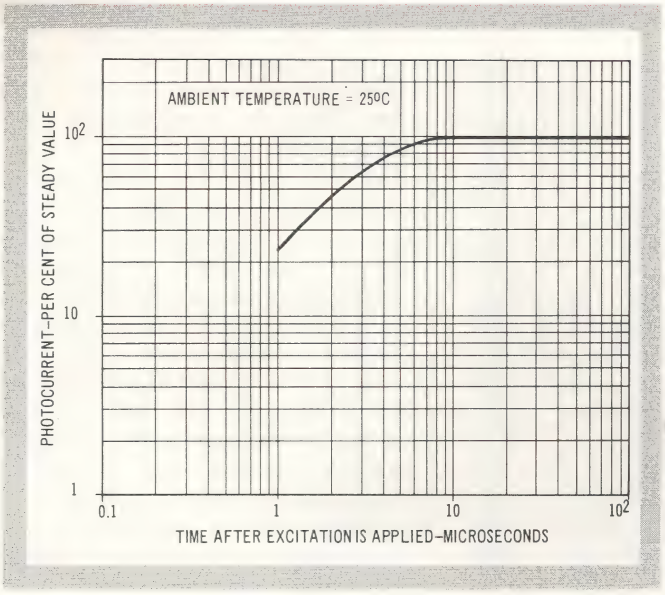


Fig. 19 - Typical Rise Characteristic of Germanium p-n Alloy Photojunction Cells.

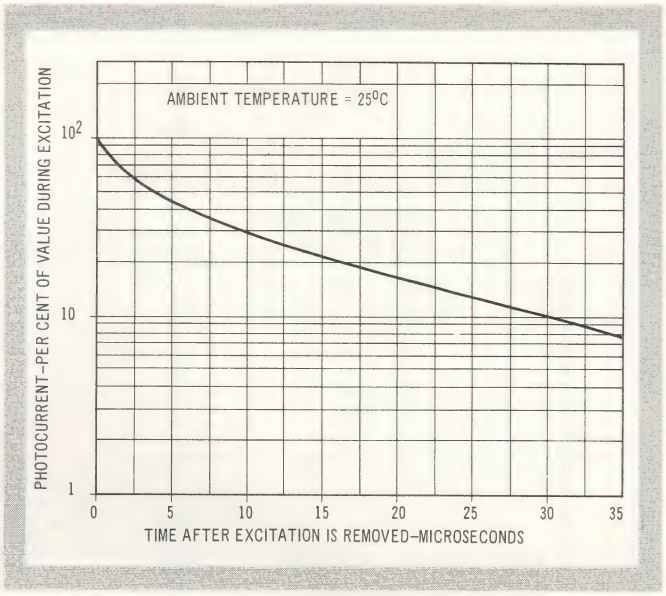


Fig. 20 - Typical Decay Characteristic of Germanium p-n Alloy Photojunction Cells.

The response of germanium photojunction cells to sudden changes in illumination is shown in Fig.19 and Fig.20. Because of its relatively fast response, the germanium photojunction cell is very useful at optical excitation frequencies well above the audio range.

Germanium photojunction cells, such as the RCA-SQ2516, have a quantum efficiency of approximately 0.45. Allowing for reflection from the germanium surface, one electron passes through the circuit for every photon incident on the junction. This type of photocell is thus intermediate in sensitivity between a single-unit phototube and a typical cadmium-sulfide photoconductive cell. The increase in sensitivity, i.e., photocurrent, is linear with the increase in illumination.

A typical spectral response characteristic for the germanium photojunction cell is shown in Fig. 27.

The germanium photojunction cell contributes relatively low noise to a circuit. A curve of equivalent noise input is shown in Fig.22.

Fig. 21 - Spectral Sensitivity Characteristic of Germanium p-n Alloy Photojunction Cell which has S-14 Response. Curve is shown for Equal Values of Radiant Flux at All Wavelengths.

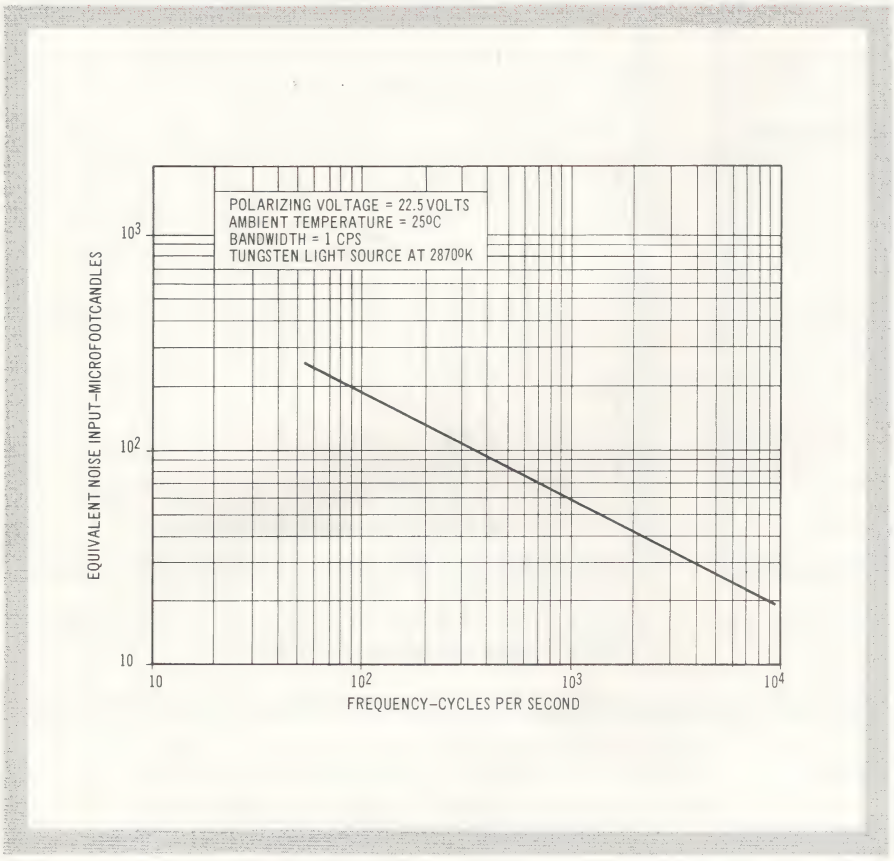


Fig. 22 - Typical Equivalent Noise Input Characteristic for Germanium p-n Alloy Photojunction Cells.

SILICON PHOTOVOLTAIC CELLS

Cells of this type are used for converting the radiant power of the sun into electrical power and for medium-speed (microsecond modulation rates) laser detection systems. Emission wavelengths of typical laser materials are listed on page 24. Silicon photovoltaic cells consist of a single crystal of the p-type into which a layer—about 0.5 micron thick—of an n-type material (frequently phosphorus) is diffused. The negative terminal is ordinarily a thin strip of solder which makes electrical contact with a family of metallic grid lines (electrodes). The positive terminal is usually the back surface of the cell. The n-on-p type cell is completed by applying a non-reflective coating of silicon monoxide to the front surface. This coating minimizes the reflection of useful radiant power from the silicon surface. Typical cell types are the 1cm x 2cm RCA-SL2205 and the 2cm x 2cm RCA-SL2206.

The advantage that n-on-p cells have over p-on-n cells is that they are far more resistant to degradation from the high-energy particles (protons and electrons) frequently encountered in space missions.

When the electrical performance of the silicon solar cell is analyzed, the curve of Fig.16 is inverted to appear as shown in Fig.23. Operation takes place in the IV quadrant of Fig.16. The curves have been redrawn to show a logarithmic presentation. Load lines for different series load resistors have been added and operation is shown at cell temperatures of 27°C, 75°C, and 125°C. The value of the load resistor is usually chosen to obtain the maximum power output from the cell for a specific condition of input illumination.

The performance of the silicon photovoltaic cell, when used for solar-power conversion, is usually described in terms of conversion efficiency which is defined as the ratio of electrical output power to incident radiant power. The load resistor is adjusted to give an output voltage of 0.46 volt which is near the maximum power transfer point. However, care should be exercised to specify the spectral content and the intensity of the illumination in describing conversion efficiency. A typical value for conversion efficiency is between 10 and 12 per cent measured under the following conditions: the light source is a tungsten-filament lamp operated at a color temperature of 2800° K and a water filter having a height of 1-¾" is placed between the cell and the light source. The water filter absorbs unwanted infrared radiation. For space applications, a solar simulator which approximates the spectral output of the sun outside of the earth's atmosphere is frequently used as the radiant energy source.

The spectral response of the silicon photovoltaic cell has its peak in the near-infrared region of the spectrum. Radiation from the sun, however, shows a peak of intensity near 4750 angstroms. Because it is desirable, for maximum conversion efficiency, that the solar cell respond to "blue" radiation, the cell is processed in such a manner that the peak of response is shifted toward the shorter wavelengths. The shift is accomplished by making the n-layer thin (for n-on-p cells) to take advantage of the light absorption properties of the silicon. A typical response characteristic for an n-on-p cell is shown in Fig.24.

The silicon photovoltaic cell is also sensitive to X-radiation. The output of a typical cell exposed to such radiation is shown in Fig.25.

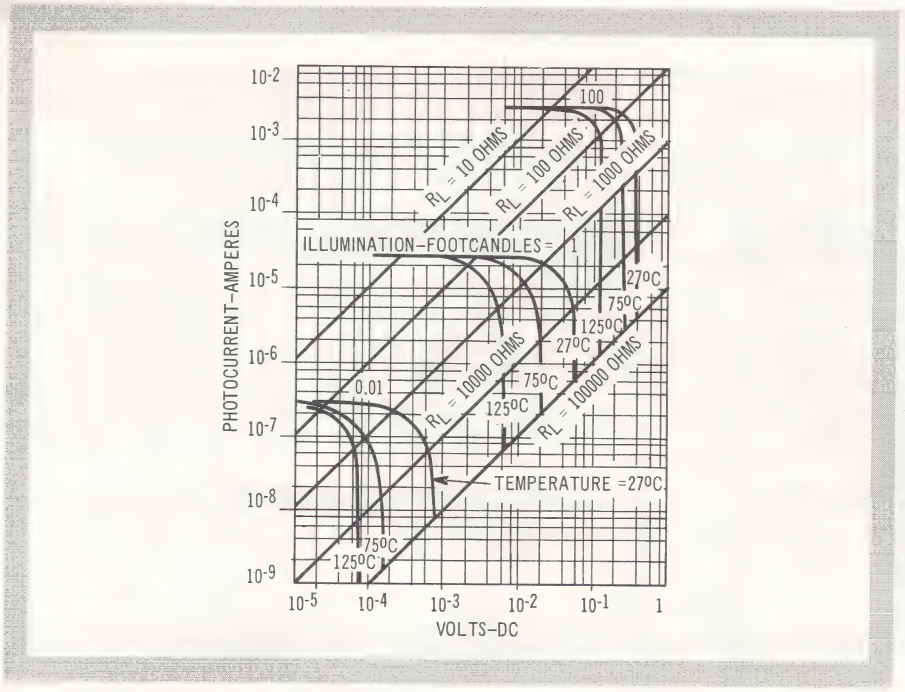


Fig. 23 - Typical Photocurrent - Voltage Relationship as a Function of Ambient Temperature of N on P Type Silicon Photovoltaic Cells. Operation is in Quadrant IV of Fig. 16.

Silicon cells are capable of generating an electrical signal when subjected to electron bombardment. The signal is proportional to the rate of electron flow and the electron energy. A minimum energy of 3.6 electron volts is required to generate the signal. The current output of the cell can be approximated by the formula

$$I = 0.8 \times \frac{\text{Electron Energy}}{3.6 \text{ ev}} \times \text{Beam Current}$$

Electron energy over 200 Kev will damage the cells permanently and degradation of the cell must be taken into account when this level is exceeded.

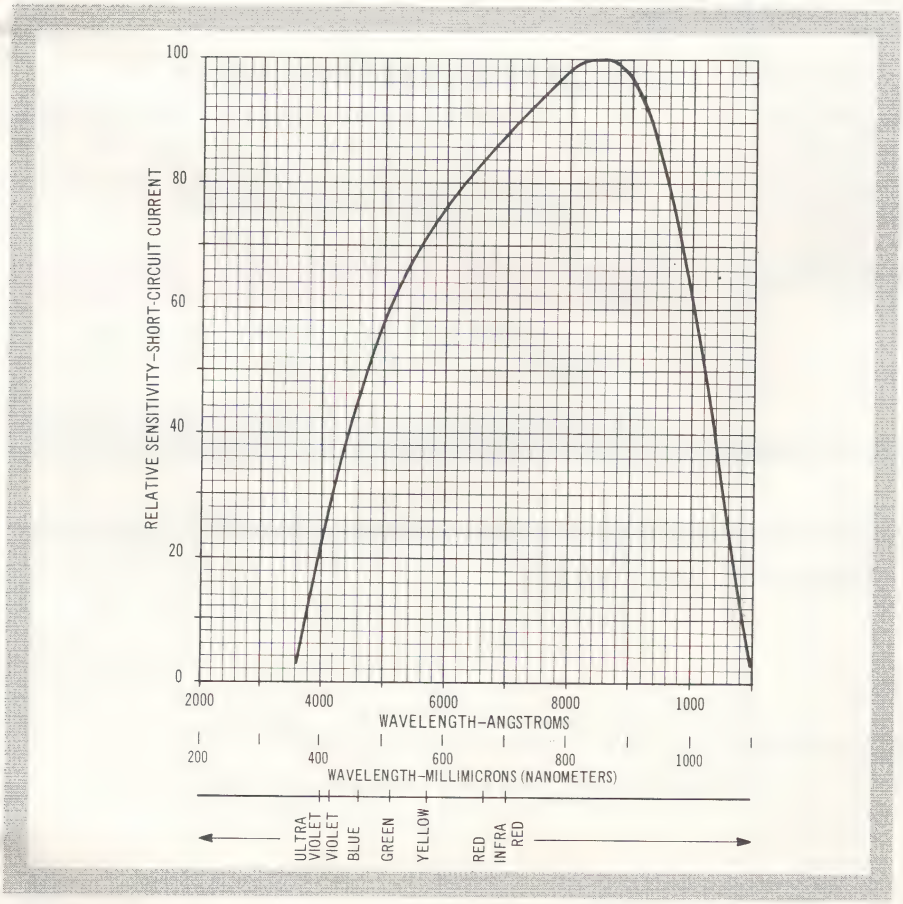


Fig. 24 - Spectral Sensitivity Characteristic of a Silicon Photovoltaic Cell. Curve is shown for Equal Values of Radiant Power at all Wavelengths.

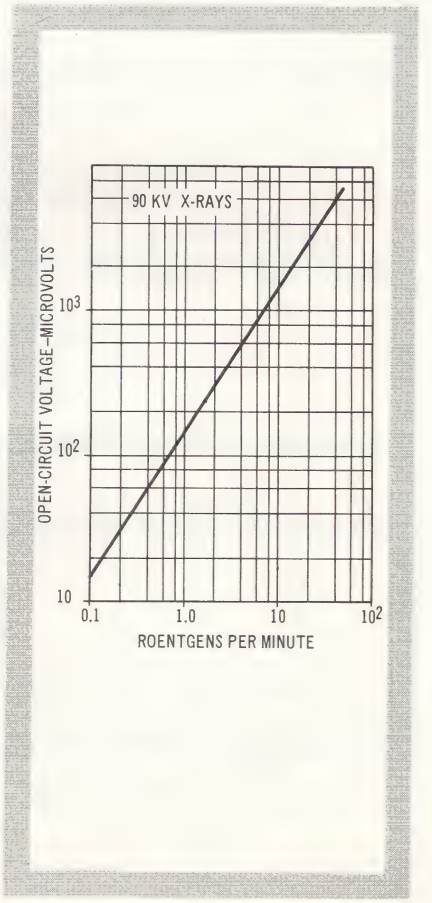
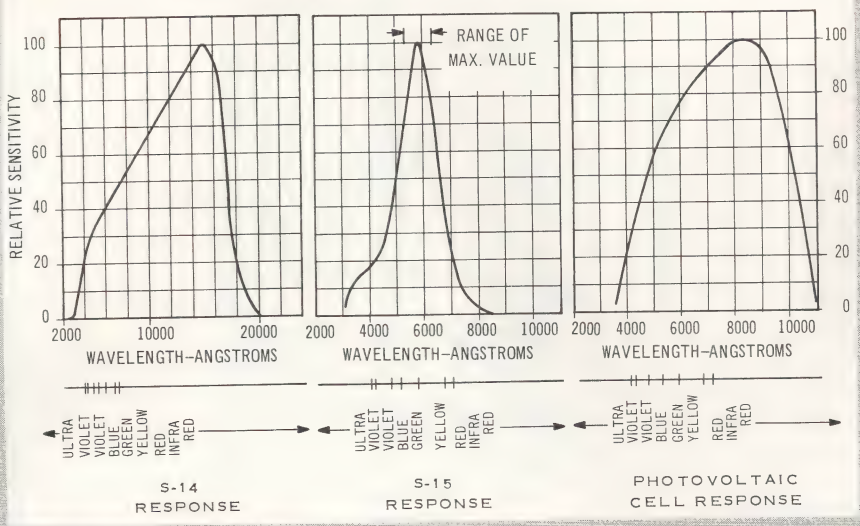


Fig. 25 - X-Radiation Sensitivity of Silicon Photovoltaic Cell.

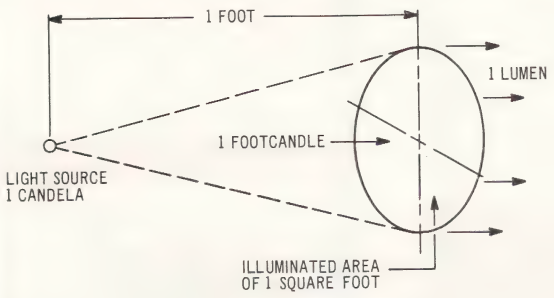
EMISSION WAVELENGTHS OF TYPICAL LASERS

Laser Material	Wavelength of Emission–Nanometers
$Al_2O_3:Cr^{3+}$	693.4
$CaF_2:Sm^{2+}$	708.2
$CaF_2:Tm^{2+}$	1,116
$CaF_2:Nd^{3+}$	1,046
$CaWO_4:Tm^{3+}$	1,116
$CaWO_4:Er^{3+}$	1,612
Nd in Glass	1,060
GaAs	840

SPECTRAL-SENSITIVITY CHARACTERISTICS



LIGHT AND WAVELENGTH UNITS USED IN PHOTOCELL MEASUREMENTS AND RATINGS



$$\text{Illumination in footcandles} = \frac{\text{Luminous Intensity in candelas}}{(\text{Distance in feet})^2} = \frac{\text{Light Flux in lumens}}{\text{Area in square feet}}$$

A light source of 1 candela emits 4π lumens.
1 Lux = 0.0929 Footcandle = 1 Lumen/Meter^2
1 Angstrom = 10^{-8} Centimeters = 10^{-10} Meters
10^4 Angstroms = 1 Micron = 1000 Millimicrons = 10^{-6} Meters
1 Millimicron = 1 Nanometer = 10^{-9} Meters
1 Nanometer = 10 Angstroms

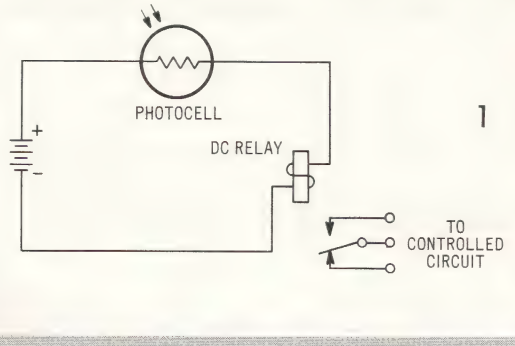
TEMPERATURE–CONVERSION SCALE

$C = 5/9 (F-32)$

CIRCUIT DIAGRAMS

BATTERY-OPERATED PHOTOCELL RELAY CONTROL CIRCUIT

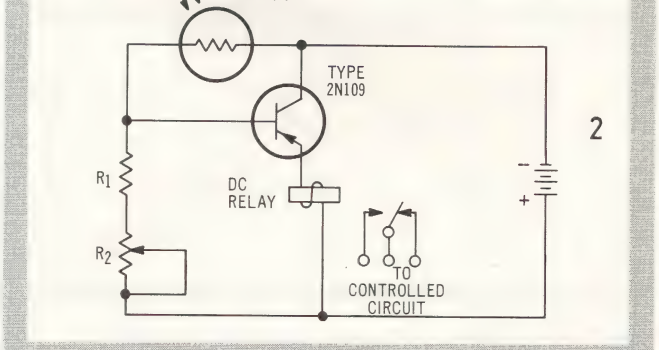
This simple circuit is capable of direct relay operation without the use of an amplifier. When light is incident on the photocell the specified relay will operate. For 6-volt operation approximately 12 footcandles of illumination on the photocell is required to activate the relay: for 12-volt operation, 4 footcandles.



RCA PHOTOCELL: TYPE 7163
BATTERY: 6- or 12-volt battery, RCA-VS040S (One, or two series connected)
DC RELAY: Advance, Type SV/1C/2200D, or equivalent, 2200 ohms, 1.5 ma operating current

BATTERY-OPERATED PHOTOCELL-TRANSISTOR RELAY CONTROL CIRCUIT

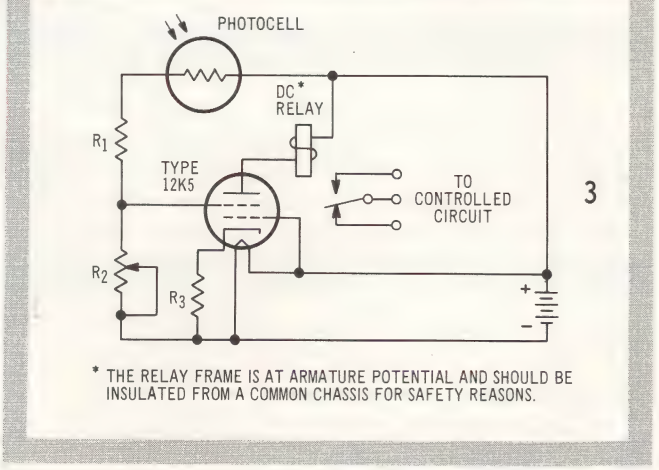
The relay in this photocell-transistor control circuit is activated when light is incident on the photocell. Illumination levels as low as 0.5 footcandle on the photocell will operate the relay. The potentiometer (R_2) permits adjustment of circuit sensitivity.



RCA PHOTOCELL: TYPE 4425
R_1: 120 ohms, 1/2 watt
R_2: 5000-ohm potentiometer
BATTERY: 6-volt battery, RCA-VS317
DC RELAY: Advance, Type SV/1C/1000D, or equivalent, 1000 ohms, 2.25 ma operating current

BATTERY-OPERATED PHOTOCELL-VACUUM TUBE RELAY CONTROL CIRCUIT

The relay is energized when light is incident on the photocell. The circuit operates with illumination levels as low as 0.1 footcandle on the photocell. The potentiometer (R_2) varies the voltage on the grid of the 12K5 and serves as a sensitivity control for the circuit. The photocell should be shielded from the light emitted by the heater of the 12K5.

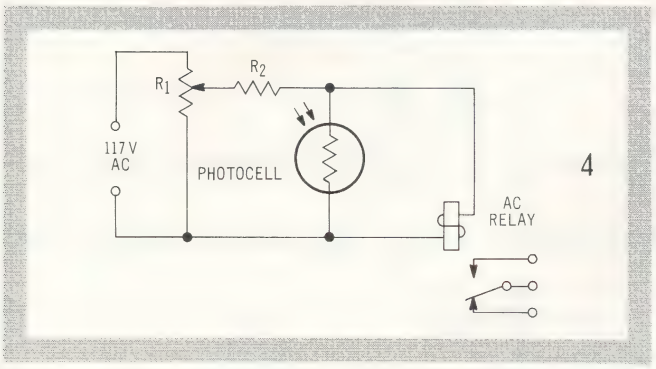


RCA PHOTOCELL: TYPE 4402
R_1: 3300 ohms, 1/2 watt
R_2: 1.5-megohm potentiometer
R_3: 56 ohms, 1/2 watt
BATTERY: 12-volt automobile storage battery
DC RELAY: Price Electric, Type 1007, or equivalent, 1000 ohms, 4.5 ma operating current

The arrows (↘) indicate that the primary characteristic of the element is designed to vary under the influence of light.

AC-OPERATED "ON-OFF" RELAY CONTROL CIRCUIT

The relay in this circuit is not energized when light is incident on the cell. When the light is interrupted or the light level drops to a predetermined value, the relay operates. The potentiometer (R_1) permits adjustment of the sensitivity of the circuit. The circuit is not intended for use in applications where the light level varies gradually because of relay chatter at the operating point.



RCA PHOTOCELL: TYPES 4403, 4404, or 7163
R_1: 10,000–ohm potentiometer, 3 watts
R_2: 18,000 ohms, 1 watt
AC RELAY: Sigma, Type 41FZ, 5000SC, or equivalent

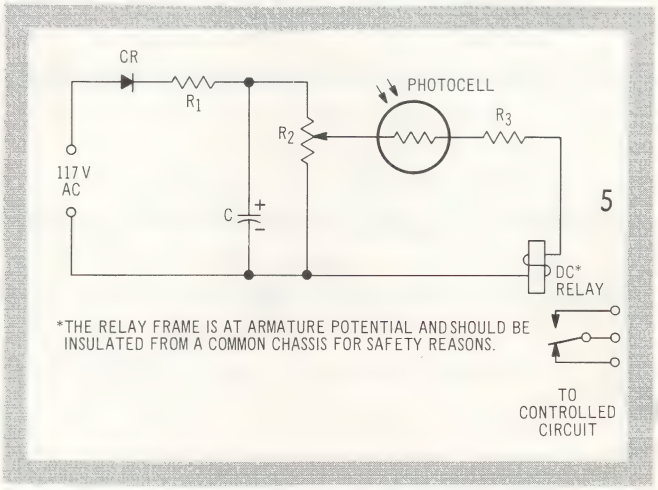
AC-OPERATED PHOTOCELL-VACUUM TUBE RELAY CONTROL CIRCUIT

The relay is energized when light is incident on the photocell. This circuit operates with light levels as low as 0.1 footcandle on the photocell and is intended for either "on-off" applications or applications in which the light level changes gradually. The potentiometer (R_5) varies the voltage on the grid of the 6AB4 and serves as a sensitivity control for the circuit. The photocell should be shielded from the light emitted by the heater of the 6AB4.

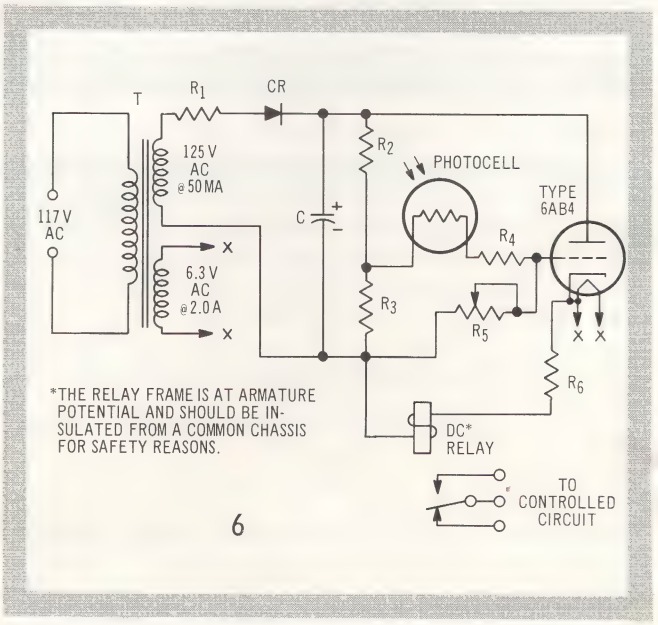
RCA PHOTOCELL: TYPE 7412
C: 20 μf, electrolytic, 250 volts (dc working)
R_1: 5.6 ohms, 1/2 watt
R_2: 10,000 ohms, 2 watts
R_3: 8200 ohms, 2 watts
R_4: 100,000 ohms, 1/2 watt
R_5: 1-megohm potentiometer
R_6: 8200 ohms, 1 watt
DC RELAY: Sigma, Type 11F-6000G, or equivalent, 6000 ohms, 2.9 ma operating current
CR: Silicon Rectifier, RCA-1N1763
T: Chicago-Stancor No. PA-8421, or equivalent

AC-OPERATED PHOTOCELL RELAY CONTROL CIRCUIT

This circuit is intended for either "on-off" applications or applications in which the light level changes gradually. Potentiometer (R_2) permits adjustment of the sensitivity of the circuit. The circuit operates with light levels as low as 1 footcandle on the photocell.

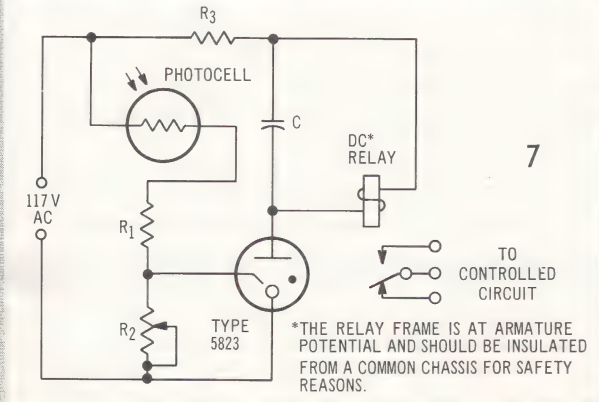


RCA PHOTOCELL: TYPES 4403, 4404, or 7163
C: 8 μf, electrolytic, 250 volts (dc working)
R_1: 5.6 ohms, 1 watt
R_2: 25,000–ohm potentiometer, 5 watts, Centralab Type WN253, or equivalent
R_3: 10,000 ohms, 1 watt
DC RELAY: Potter and Brumfield, Type RS5D, or equivalent, 10,000 ohms, 2.5 ma operating current
CR: Silicon Rectifier, RCA–1N1763



AC-OPERATED PHOTOCELL-GLOW DISCHARGE-TUBE RELAY CONTROL CIRCUIT

The relay is energized when light is incident on the photocell. The capacitor (C) prevents relay chatter: the potentiometer (R_2) permits adjustment of the starter-electrode voltage of the glow-discharge-triode type 5823 and controls the sensitivity of the circuit. The circuit operates with illumination levels as low as about 0.1 footcandle on the photocell. The photocell should be shielded from the light emitted from the 5823 during discharge.



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RCA PHOTOCELL: TYPE 4402
C: 16 μf, 150 volts (dc working)
R_1: 180,000 ohms, 1/2 watt
R_2: 1-megohm potentiometer, 2 watts
R_3: 1200 ohms, 1/2 watt
DC RELAY: Potter and Brumfield, Type LB-5, or equivalent, 10,000 ohms, 4.5 ma operating current

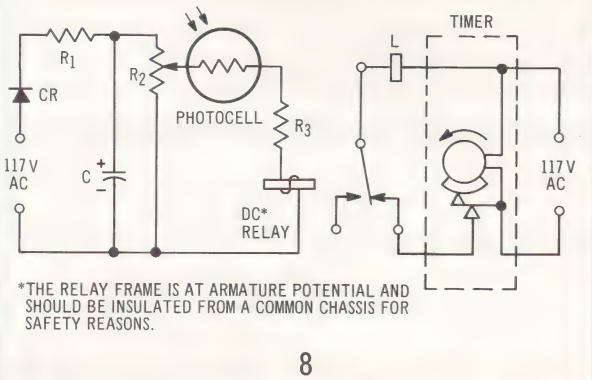
CONTROL CIRCUIT REQUIRING NO EXTERNAL POWER SUPPLY

This control circuit requires no associated power supply. When the cell is illuminated, it converts incident light into electrical power to activate the specified relay. Light levels as low as about 25 footcandles on the cell operate the relay. The center contact of the specified relay is in a "floating" neutral position. The polarity of the photocell signal will determine which relay contact closes.

The arrows (↘) indicate that the primary characteristic of the element is designed to vary under the influence of light.

PHOTOCELL CONTROLLED "TURN-ON", TIME CONTROLLED "TURN-OFF" UNIT

This circuit is useful in store-window advertising and similar display applications. The relay is activated when light is incident on the photocell during daylight. The specified 24-hour timer unit is adjusted manually so that its contacts will close in early afternoon. As darkness comes, the relay arm is released and current flows through the load (L). Current will continue to flow until the timer cycle is completed.



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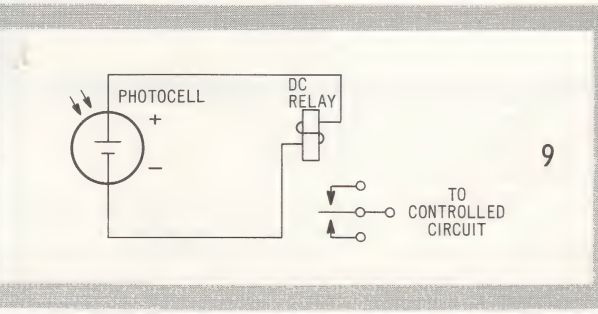
RCA PHOTOCELL: TYPES 4403, 4404, or 7163
C: 8 μf, electrolytic, 250 volts (dc working)
L: Load
R_1: 5.6 ohms, 1 watt
R_2: 25,000-ohm potentiometer, 5 watts, Centralab Type WN253, or equivalent
R_3: 10,000 ohms, 1 watt
DC RELAY: Potter and Brumfield, Type RS5D, or equivalent, 10,000 ohms, 2.5 ma operating current
CR: Silicon Rectifier, RCA-1N1763
TIMER: Tork Time Controls, Model No. 919, 24-hour timer switch, or equivalent.



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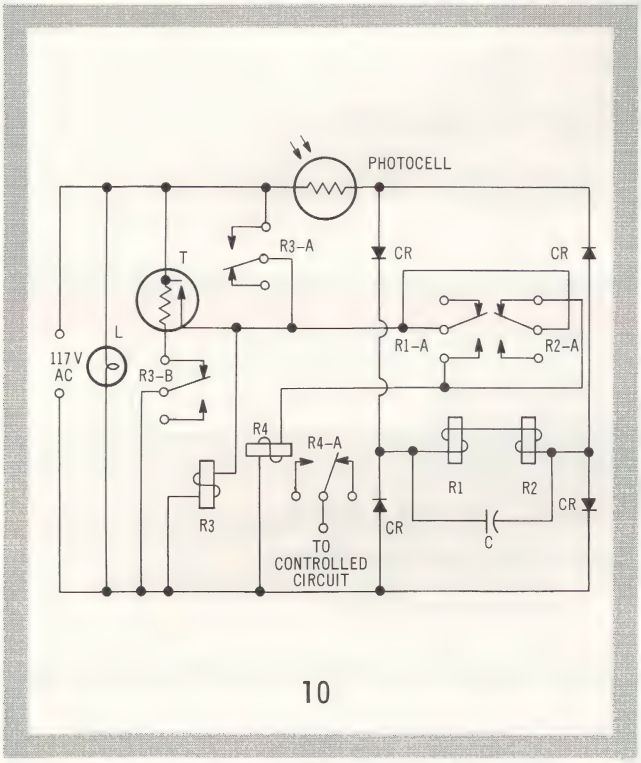
RCA PHOTOVOLTAIC CELL: TYPE SL2206
DC RELAY: Barber-Colman, Type AYLZ 7306-100, or equivalent. Pull-in voltage 0.155 volt; pull-in current 280 microamperes.

LIGHT-CONTROLLED LIMIT CIRCUIT

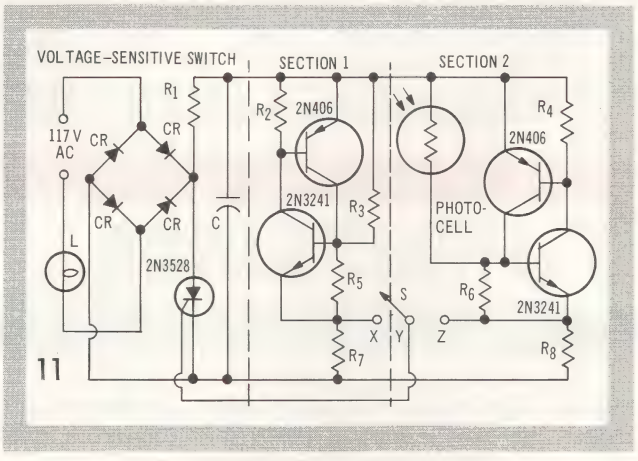
In this limiting circuit, the Relay R_4 is energized whenever the light level on the photocell exceeds a preselected level or falls below another preselected level. The thermal relay (T), which closes after a 1-second delay, is employed to prevent starting transients from activating the circuit before the light from the lamp reaches its full output. When this light level is established, contact R2-A opens. Contact R3-B of relay R_3 is initially closed. When the thermal relay closes, the contact opens removing the voltage across this relay and contact R3-A closes, holding in the circuit. Contact R1-A of relay R_1 operates when the light level on the photocell exceeds its preselected level. Contact R2-A of relay R_2 closes when the light level falls below its preselected level. Under either operating condition relay R_4 is thus energized.



RCA PHOTOCELL: TYPE 7163
C: 1 μf, 200 volts (dc working)
L: 117V AC lamp
RELAY R_1: Potter and Brumfield, Type RS5D, or equivalent, 10,000 ohms, 2.5 ma operating current
RELAY R_2: Advance, Type SV/1C/10,000D, or equivalent, 10,000 ohms, 0.7 ma operating current
RELAY R_3: Guardian, Type 1200-G115, or equivalent
RELAY R_4: Advance, Type GHA/1C/115AC, or equivalent
T: Thermal Relay: Tungsten, Type X-263A, or equivalent
CR: Silicon Rectifiers, RCA-1N3194

PHOTOCELL-SOLID STATE RELAY CIRCUIT

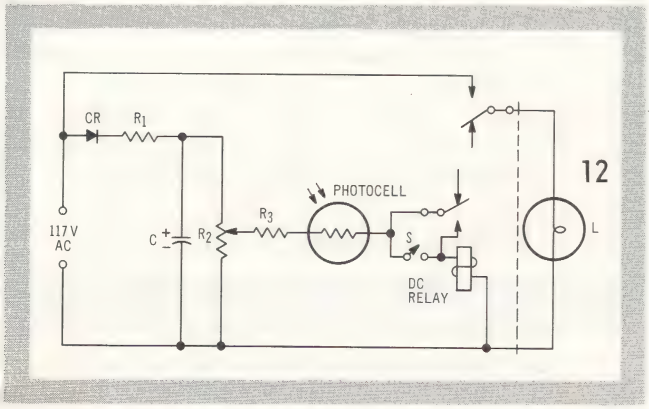
The load in this circuit is energized when the silicon controlled-rectifier type 2N3528 conducts. When switch (S) connects point Y to X, the load is energized by a decrease in light level on the photocell. The transistor portion of the circuit, which acts as a voltage-sensitive switch, may be separated into two sections. When the photocell is in the dark and point Y is connected to point X, the capacitor (C) charges to approximately 8 volts before sufficient current is applied to the base of the 2N3241 of the first section to cause this transistor combination to conduct. When it conducts an output pulse is developed across its 15-ohm load resistor which in turn triggers the 2N3528 causing it to conduct and thereby energize the load (L). The high impedance of the photocell in the dark prevents sufficient current from being applied to the base of the 2N3241 of the second section to allow this transistor combination to conduct. When the photocell is illuminated, its impedance drops to a value that is much less than the 56,000-ohm resistor of the first transistor combination. The second section thus conducts before the first, and in doing so reduces the voltage across the capacitor (C) so that insufficient current is available to fire the transistors of the first section. Under these conditions, the 2N3528 is not triggered and the load is not energized. When points Y and Z are connected, the load is energized by an increase in light level on the photocell, and circuit operation is reversed.



RCA PHOTOCELL: TYPE 7163
C: 0.22 μf, 12 volts (dc working)
L: Lamp load, 150 watts max.
R_1: 4,700 ohms, 2 watts
R_2; R_4: 150 ohms, 1/2 watt
R_3: 56,000 ohms, 1/2 watt
R_5, R_6: 4,700 ohms, 1/2 watt
R_7, R_8: 15 ohms, 1/2 watt
S: Switch
CR: Silicon Rectifiers, RCA-1N2861

ANNUNCIATOR SYSTEM (RESPONDS TO DARKNESS)

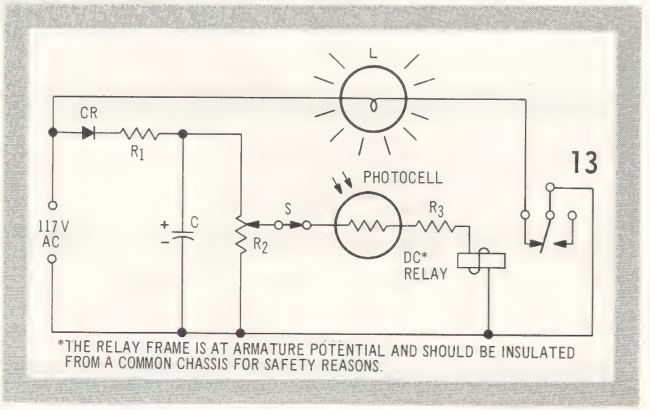
When the photocell is illuminated and the switch (S) is manually set, photocurrent will flow through the photocell and the relay coil. The lamp is off. When the illumination is removed, the relay opens, and connects the indicator lamp (L) across the ac line. The lamp will remain on even though the photocell is re-illuminated until the switch is manually reset to re-energize the relay.



RCA PHOTOCELL: TYPE 7163
C: 8 μf, electrolytic, 250 volts (dc working)
L: 117 V AC lamp
R_1: 5.6 ohms, 1 watt
R_2: 25,000-ohm potentiometer, 5 watts, Centralab Type WN253, or equivalent
R_3: 10,000 ohms, 1 watt
S: Push-button switch, SPST (Normally Open)
CR: Silicon Rectifier, RCA-1N1763
DC RELAY: Potter and Brumfield, Type GB11D, or equivalent, 10,000 ohms, 3.53 ma operating current

ANNUNCIATOR SYSTEM (RESPONDS TO LIGHT)

The indicator lamp (L) is initially off with the circuit in the dark. When the photocell is illuminated, the relay is energized and connects the lamp across the ac line. The lamp illuminates the photocell. The lamp will remain on until the push-button switch is manually reset thereby opening the circuit and allowing the relay to drop out.



RCA PHOTOCELL: TYPE 7163
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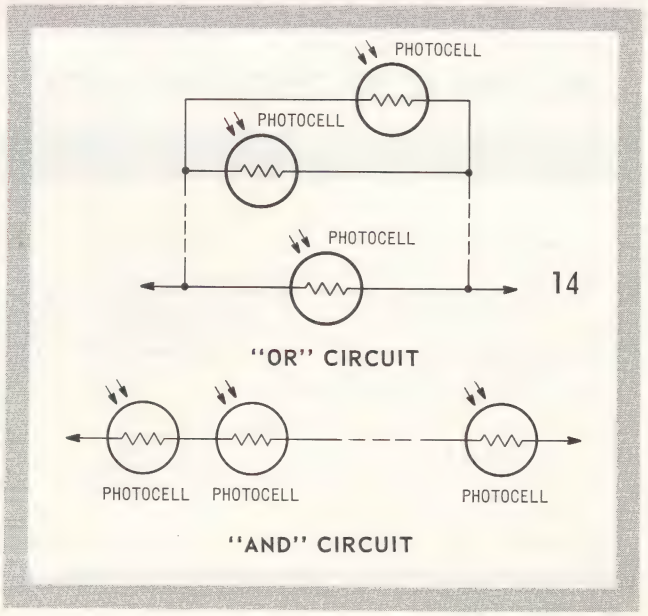
L: 117 V AC lamp
R_1: 5.6 ohms, 1 watt
R_2: 25,000-ohm potentiometer, 5 watts, Centralab Type WN253, or equivalent
R_3: 10,000 ohms, 1 watt
S: Push-button switch, SPST (Normally Closed)
CR: Silicon Rectifier, RCA-1N1763
DC RELAY: Potter and Brumfield, Type RS5D, or equivalent, 10,000 ohms, 2.5 ma operating current

"OR" AND "AND" LOGIC SYSTEMS

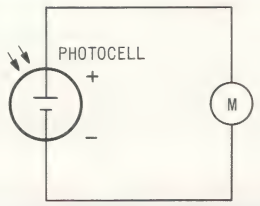
These systems have two or more light inputs and a single two-terminal electrical output. In the "or" circuit, a light signal applied to any one of the photocells decreases the impedance of the circuit. In the "and" circuit, a light signal applied simultaneously to all of the photocells decreases the impedance of the circuit.

The arrows (↙) indicate that the primary characteristic of the element is designed to vary under the influence of light.



LIGHT-INTENSITY METER

The light-intensity meter requires the minimum of components, and is well suited for compact light-measurement equipment. The circuit requires no external power supply and has found use in such industrial applications as the measurement of density of thin evaporated films. If another meter movement is used, the meter impedance should be low so that the current is near the short-circuit value at the light level of interest.



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RCA PHOTOVOLTAIC CELL: TYPE SL2206
M: Volt-ohm-ammeter, RCA Type WV-38A

LIGHT SOURCE	CALIBRATION APPROX.
Tungsten Lamp (2870 °K)	29 μa/fc

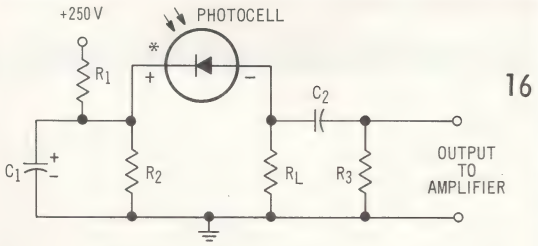
MULTI-POLE, MULTI-POSITION SWITCH

This system permits a choice of switching operations to be performed when a punched card having selected perforations is placed between the light source and the photocell bank.

The arrows (⇝) indicate that the primary characteristic of the element is designed to vary under the influence of light.

SIMPLE VOLTAGE-DIVIDER ARRANGEMENT FOR RCA PHOTOJUNCTION CELLS

This simple arrangement provides the necessary voltage and output impedance for coupling RCA Photojunction cells to amplifier circuits.



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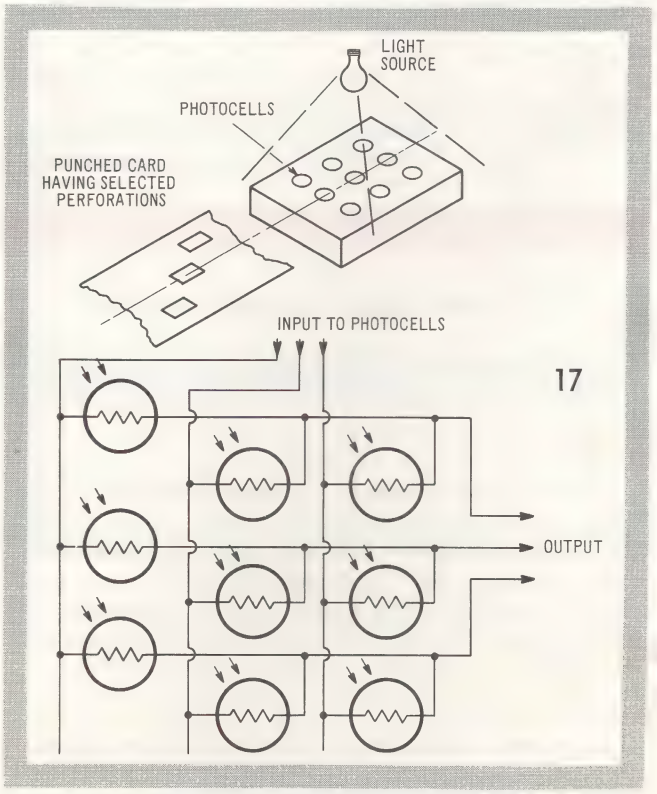
* THE POSITIVE VOLTAGE SHOULD BE APPLIED TO THE LEAD NEAREST THE RED DOT ON THE CASE.

RCA PHOTOCELL: TYPE SQ2516
C_1: 1 μf, electrolytic, 50 volts (dc working)
C_2: 0.047 μf , 100 volts (dc working)
R_1: 220,000 ohms, 1/2 watt
R_2: 22,000 ohms, 1/2 watt
R_3: 1 megohm, 1/2 watt
R_L: 100,000 ohms, 1/2 watt



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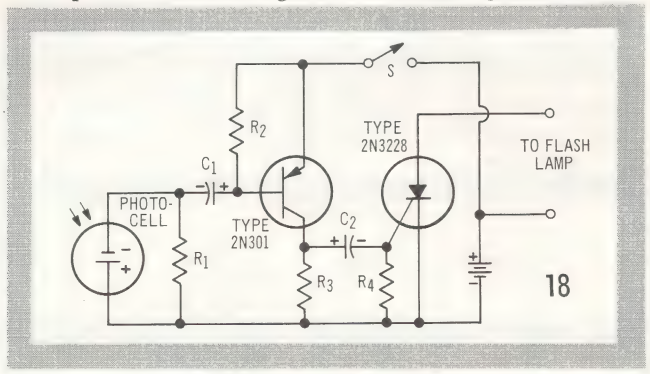
RCA PHOTOCELLS: TYPES 4402 or 4425

PHOTOGRAPHIC-FLASH SLAVE UNIT

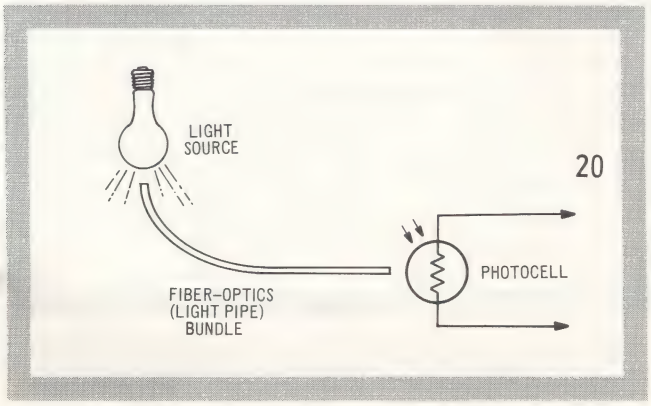
In this simple circuit the light pulse from the main flash lamp or electronic flash unit is converted into an electrical pulse which is amplified and fires the silicon controlled-rectifier. The current flowing through the controlled rectifier, in turn, fires the slave flash lamp. The switch (S) should be closed before inserting the flash lamp in the circuit to prevent premature flashing due to switching transients.



RCA PHOTOCELL: TYPE SL2206
C_1: 100 μf, electrolytic, 6 volts
C_2: 15 μf, electrolytic, 6 volts
R_1: 100 ohms, 1/2 watt
R_2: 1000 ohms, 1/2 watt
R_3: 68 ohms, 1/2 watt
R_4: 1000 ohms, 1/2 watt
S: On-off switch
BATTERY: 6-volt battery

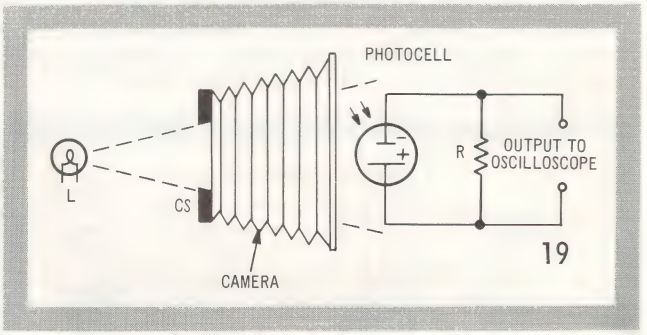
PHOTOCELL-LIGHT PIPE SYSTEMS

It is sometimes inconvenient or impractical to locate the photocell at a point where light is to be detected. Under such conditions, light may be "piped" to the photocell by a fiber-optics bundle.



CAMERA SHUTTER-TIME MEASUREMENT UNIT

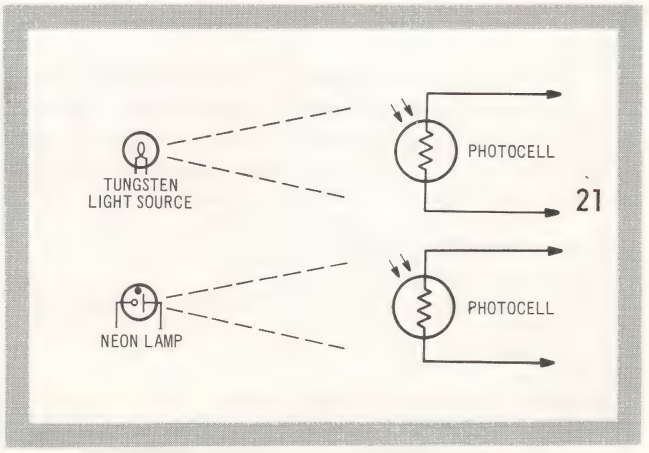
When the shutter in this system is opened, light passes through the opening and falls on the photovoltaic cell. An electrical pulse is generated by the cell. By observing the time duration of the pulse on a calibrated oscilloscope, the shutter speed of the camera may be determined.



RCA PHOTOCELL: TYPE SL2205
L: Lamp
CS: Camera Shutter
R: 470 ohms, 1/2 watt

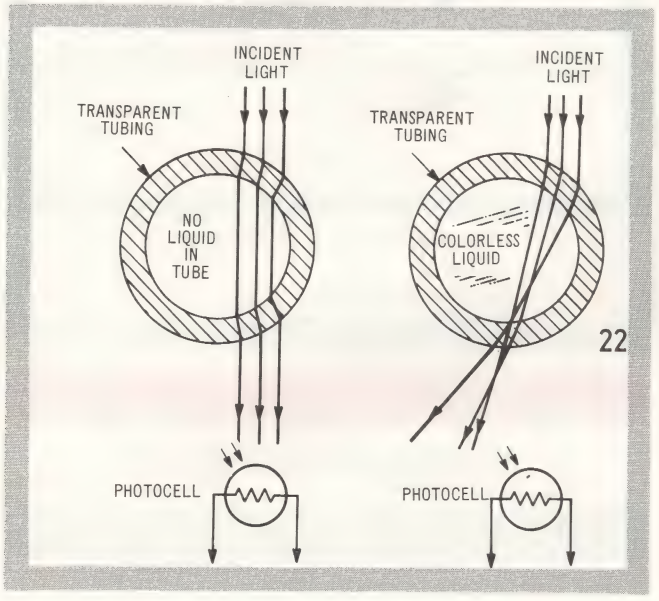
SWITCHING SYSTEMS

Switching systems employing photocells are advantageous in that they inherently provide low switching noise, freedom from moving parts, and have electrically isolated input and output signals. The systems may use either tungsten-filament or neon light sources. When light is incident on the photocell its impedance drops and the switch is considered "on". When the photocell is not illuminated its impedance is high and the switch is considered "off".



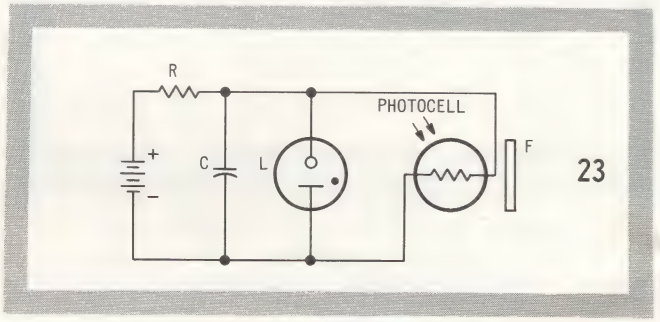
COLORLESS-LIQUID DETECTION SYSTEM

The presence or absence of a colorless liquid passing through a transparent tube may be detected by this system. The photocell is positioned initially so that light passing through an empty tube is incident on the photocell. When a colorless liquid passes through the tube, the light beam is deflected because of the change in the index of refraction of the system and the photocell is no longer illuminated.



AUTOMATIC LIGHT FLASHER

When darkness falls, the neon lamp (L) periodically flashes on and off. At dawn, the neon lamp automatically stops flashing. The photocell acts as a low impedance when illuminated during the day. Under these conditions the voltage drop developed across the neon lamp is insufficient to cause it to fire. When the light level drops to low value, the impedance of the photocell becomes high and the voltage drop is sufficient to fire the neon lamp. The light level required to fire the lamp may be adjusted by means of a light attenuator positioned before the photocell.

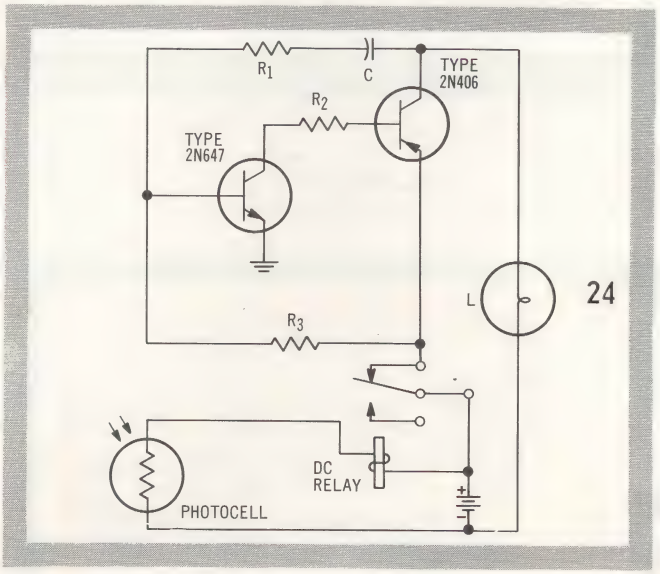


RCA PHOTOCELL: TYPE 7412
C: 1 μf, 100 volts (dc working)
F: Light-attenuating filter or baffle
L: NE-2 neon lamp
R: 1 megohm, 1/2 watt
BATTERY: 90-volt "B" battery, RCA-VS090

LIGHT-CONTROLLED BARRIER LIGHT FLASHER

The relay of this circuit is activated and opens the lamp circuit during daylight hours. When darkness falls, the lamp (L) flashes on and off periodically. The flash "on" time of the lamp is about 0.2 second and the "off" time is about 0.6 second.

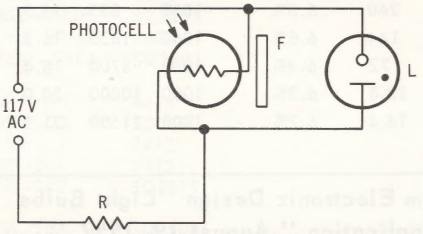
RCA PHOTOCELL: TYPE 7163
C: 3 μf, paper, 25 volts (dc working)
L: General Electric lamp, Type GE-1867, 4 volts, 60 ma
R_1: 10,000 ohms, 1/2 watt
R_2: 1200 ohms, 1/2 watt
R_3: 0.82 megohms, 1/2 watt
BATTERY: 6-volt battery, RCA-VS103
DC RELAY: Advance, Type SV/1C/2200D, or equivalent, 2200 ohms, 1.5 ma operating current



The arrows (↘↘) indicate that the primary characteristic of the element is designed to vary under the influence of light.

REMOTE INDICATOR

The photocell has very high impedance in darkness and low impedance when fully illuminated. When illumination on the photocell is removed, the cell impedance increases and the voltage drop developed across the photocell is sufficient to fire the indicator neon lamp (L). The light level required to fire the neon lamp may be adjusted by means of a light attenuator positioned before the photocell.



RCA PHOTOCELL: TYPE 7412
F: Light-attenuating filter or baffle
L: NE-2 neon lamp
R: 220,000 ohms, 1/2 watt

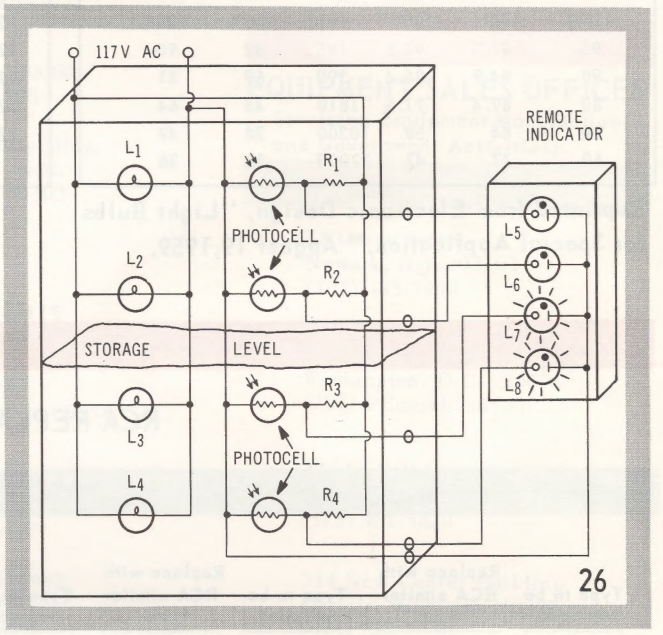
REMOTE POTENTIOMETER

This circuit provides a means of remotely adjusting the volume of public address or home audio systems. Good frequency response is obtained because the leads in the signal circuit may be as short as desired while the control-lamp leads can be of practically any desired length. The specified lamps have large diameter filaments to minimize 120 cps hum. The electrostatic shield between the lamps and the cells prevents hum from being coupled into the signal circuit. A dc power supply for the lamps may be used if minimum hum is required. The input leads are shielded to minimize capacitive coupling between the input and output signal. Varying the potentiometer (R) changes the voltage distribution across the lamps and the respective illumination on the photocells. Maximum voltage attenuation occurs when the potentiometer arm is in position 1 and minimum attenuation in position 2.

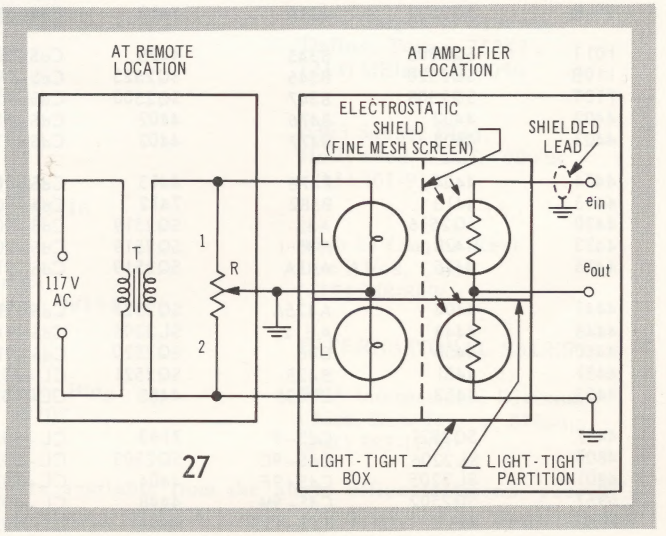
RCA PHOTOCELLS: TYPE 4402
L: General Electric lamps, Type GE-47, 6.3 volts, 0.15 amp
R: 2-ohm potentiometer, 25 watts, Ohmite Model No. 0141, or equivalent
T: Chicago-Stancor No. P6456, or equivalent

STORAGE-LEVEL REMOTE INDICATOR

This circuit provides a means of remotely observing the fill-level of a storage bin. When the photocells are illuminated, the voltage drop across the cells is insufficient to fire the indicator neon lamps. As the storage level increases, light is excluded in sequence from photocells. As a result, the voltage drops across the cells increase, and the neon lamps fire in sequence to indicate the storage level.



RCA PHOTOCELLS: TYPE 7412
R_1 through R_4: 220,000 ohms, 1/2 watt
L_1 through L_4: 117V AC lamps
L_5 through L_8: NE-2 neon lamps



CHARACTERISTICS OF TUNGSTEN-FILAMENT LAMPS

Voltage E (%)	Current I (%)	Power N (%)	Life (%)	Lumen (%)	Lumen / Watt (%)
150	122	184	0.51	410	225
140	118	166	1.3	325	196
130	114	148	3.3	250	169
120	109.5	131.5	9.4	189	144
110	104.9	115.9	29	139	121
105	102.5	107.6	53	119	110
100%	100%	100%	100%	100%	100%
95	97.5	92.6	195	82	90
90	94.9	85.4	390	69	81
80	89.4	71.5	1810	45	64
70	84	59	10300	28	49
60	77	47	77000	16	36

Reprinted from Electronic Design, "Light Bulbs for Special Application," August 19,1959.

RATED VALUES OF COMMON LIGHT BULBS

Voltage E (Volts)	Current I (Amp.)	Power N (Watts)	Resist. R (Ohms)	R (E = 0%) / R (E = 100%) (%)	Life (Hours)	Lumen	Lumen / Watt	Temperature (°F)
120	0.025	3	4800	8.5%				3600
120	0.050	6	2400	8.0%	1500	41	6.8	3860
120	0.083	10	1440	7.9%	1500	79	7.9	3900
120	0.125	15	960	7.6%	1000	140	9.3	4050
120	0.208	25	580	7.3%	1000	260	10.5	4190
120	0.333	40	360	6.8%	1000	465	11.7	4490
120	0.50	60	240	6.8%	1000	835	13.9	4530
120	0.83	100	144	6.6%	1000	1630	16.3	4670
120	1.67	200	72	6.4%	1000	3700	18.4	4750
120	4.17	500	28.8	6.3%	1000	10000	20.0	4850
120	8.34	1000	14.4	6.2%	1000	21500	21.5	4930

Reprinted from Electronic Design "Light Bulbs for Special Application," August 19, 1959.

RCA REPLACEMENT GUIDE

Type to be replaced	Replace with RCA similar type	Type to be replaced	Replace with RCA similar type	Type to be replaced	Replace with RCA similar type	Type to be replaced	Replace with RCA similar type	Type to be replaced	Replace with RCA similar type
100A	SQ2526	7412	7412	CdS-125	4450	CL-605L	4402	IEC-405	4423
100B	SQ2526	8100	4423	CdS-126	4451	CL-607	7412	IEC-501	4402
100C	4403	8142	SQ2524	CdS-134	7163	CL-702	SQ2529	IEC-504	SQ2500
101A	SQ2525	8143	4423	CdS-701	SQ2525	CL-702L	SQ2519	IEC-505	SQ2524
101B	SQ2527	8318	7412	CdS-702	SQ2521	CL-705	SQ2508	IEC-701	7412
101T	SQ2508	8345	4425	CdS-703	SQ2526	CL-705HL	SQ2508	IEC-702	SQ2519
110B	SQ2520	8346	SQ2523	CdS-704	SQ2527	CL-707	SQ2508	K20	SQ2502
110T	SQ2508	8347	SQ2500	CdS-710	SQ2525	CL-802	7163	MBI P/N 11675	4403
4402	4402	8476	4402	CdS-711	SQ2521	CL-805	4403	MKY-251	7163
4403	4403	8477	4402	CdS-712	SQ2526	CL-807	4403	N2009	SL2205
4404	4404	8478	4413	CdS-901	7163	D1767	4448	NSL-5	7163
4413	4413	8582	7412	CdS-902	4448	DT-877D	SQ2524	NSL-5A	7163
4420	SQ2516	A33	SQ2519	CdS-903	4453	DT-877F	4423	NSL-6	4404
4423	4423	A35	SQ2519	CdS-904	4403	DT-877H	4404	NSL-6A	4404
4425	4425	A35A	SQ2519	CdS-910	7163	DT-877M	7163	NSL-7	4403
4442	4404	A425A	SQ2521	CdS-911	4448	DT-877Q	SQ2528	NSL-7A	4403
4448	4448	AE122	SL2206	CdS-912	4453	EM-1505	SQ2508	NSL-45	7163
4450	4450	B46	SQ2520	CdS-913	4403	IEC-200	4402	NSL-46	4404
4451	4451	B425	SQ2521	CL-402	SQ2528	IEC-201	7412	NSL-47	4403
4453	4453	B1035	4453	CL-407	7412	IEC-202	SQ2519	NSL-52	SQ2527
4457	SQ2521	CdS-9	7163	CL-505	4423	IEC-203	SQ2508	NSL-53	SQ2520
4800	SL2206	CdS-9C	SQ2503	CL-505L	SQ2524	IEC-204	SQ2524	NSL-54	SQ2520
4801	SL2205	CdS-9F	4404	CL-507	4423	IEC-205	4423	NSL-55	SQ2525
6957	SQ2502	CdS-9M	4448	CL-602	SQ2528	IEC-400	4402	NSL-56	SQ2521
7163	7163	CdS-123	4403	CL-605	7412	IEC-401	7412	NSL-57	SQ2526

RCA REPLACEMENT GUIDE

Type to be replaced	Replace with RCA similar type
NSL-62	SQ2519
NSL-63	SQ2519
NSL-65	SQ2508
NSL-66	SQ2508
NSL-67	SQ2508
NSL-531	4425
NSL-561	4423
NSL-703P	SL2205
OED-5H6	4404
OED-5H64	SQ2503
ORP-11	4425
ORP-30	SQ2502
ORP-60	7412
PB-201	7412
PB-202	SQ2519
PB-203	SQ2508
PB-204	4425
PB-205	4423
PD-3L	SQ2516
PD-401	7412
PD-402	SQ2519
PD-403	SQ2508
PRX 25	SQ2519
RPY 27	4403
S1020 GE	SL2205
S2020 GE	SL2206
SL2205	SL2205
SL2206	SL2206
SQ2500	SQ2500
SQ2502	SQ2502
SQ2503	SQ2503
SQ2508	SQ2508
SQ2516	SQ2516
SQ2519	SQ2519
SQ2520	SQ2520
SQ2521	SQ2521
SQ2523	SQ2523
SQ2524	SQ2524
SQ2525	SQ2525
SQ2526	SQ2526
SQ2527	SQ2527
SQ2528	SQ2528
SQ2529	SQ2529
V 97-1	7163
V 97-2	4448
V 97-3	4404
V 97-4	4450
V 97-5	4451
VT-301	SQ2519
VT-302	SQ2519
VT-303	SQ2508
VT-304	SQ2508
VT-40L	SQ2527
VT-401	SQ2526
VT-402	SQ2525
Y 1144	4453
Z-2755-1	SQ2519
Z-2963-1	SQ2520

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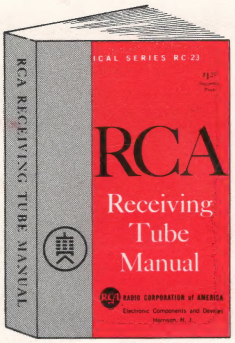
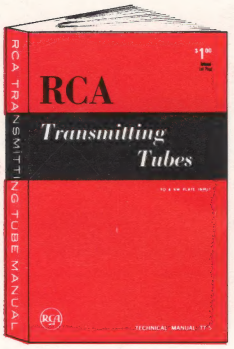
RCA RECEIVING TUBE
MANUAL RC-23



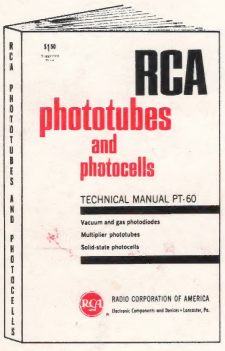
RCA TRANSMITTING
TUBE MANUAL TT-5



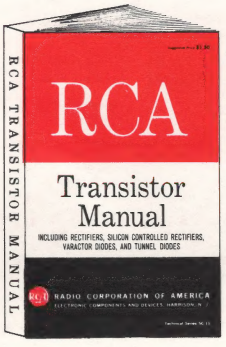
SEMICONDUCTOR
PRODUCTS
HANDBOOK HB-10

RCA SEMICONDUCTOR PRODUCTS HANDBOOK HB-10 VOL. 1
RCA SEMICONDUCTOR PRODUCTS HANDBOOK HB-10 VOL. 2
RCA SEMICONDUCTOR PRODUCTS HANDBOOK

RCA Technical Publications



RCA PHOTOTUBE
MANUAL PT-60



RCA TRANSISTOR
MANUAL SC-11

ELECTRON TUBE
HANDBOOK HB-3

RCA PHOTOCELLS ARE AVAILABLE FROM
YOUR RCA INDUSTRIAL TUBE DISTRIBUTOR